Tampere University

Ali Zaheer

SITUATIONAL AWARENESS THROUGH IOT SENSORS

A smart healthcare system as a use case

Electrical Engineering
Master’s Thesis
September 2019

ABSTRACT

Ali Zaheer
Master's Thesis
Tampere University
Master of Science (Technology)
September 2019

Abstract – Emerging technologies of the Internet of Things are getting increasingly significant and to some extent essential as well to the society we are living in. These technologies have shown ability over the time to be implemented in a number of different fields, for instance, Smart Home, Smart Building, Smart City, Smart Retail, Smart Supply Chain, Smart Farming, Smart Grid, Industrial Internet and many more. Incorporation of Internet of Things technologies in the healthcare sector has potential to benefit not only medical related enterprises but at the same time it can improve the overall health and well-being of individuals as well. The deployment of IoT integrated systems has to deal with fairly heterogeneous environments that consist of a large number of sensors and actuators which all can be quite different from one another in many aspects. For example, they can use different operating systems and can have different hardware architecture. Such sensors are sometimes used for situational awareness of the surrounding and for making the individuals interact better with their environment. Such variety of applications and tasks poses a problem for system designers and developers on the choice of the most suitable technology to be employed to accomplish a specific task. This thesis explores the potential of Internet of Things technologies in the medical sector. We used analytical hierarchical process to have a kind of situational awareness through IoT technologies. As an use case, a healthcare system was considered for elderly people with neurological problems who need special care – people suffering with dementia for example. At the same time we have taken into account for the proposed system that it would enable regular people track and monitor their usual activities with a focus on improving the quality of life and enhancing their overall well-being. It is of prime importance for the system designers and developers that they have an idea about the potential IoT technologies and applications that can help this cause. We have considered eleven different IoT technologies to select from for the proposed paradigm. The decision of selecting the most appropriate technology obviously depends upon different criteria. Every IoT technology has its pros and cons. According to the needs of the proposed healthcare system, we have constructed a multi-criteria hierarchical model to assess the potential of those eleven IoT technologies for the healthcare system and chosen the best one based on set criteria and sub criteria. A 4-tier Analytical Hierarchical model is used to compare those technologies in terms of their quality of service or effectiveness, their acceptability and from the cost perspective. These criteria are then further divided into sub-criteria and the technologies are compared with respect to these ten sub-criteria to have a more thorough and comprehensive analysis. For these comparisons, quantitative data were collected from the internet including IEEE articles, and some of the comparisons are purely subjective. The results indicate that wide-area low-power solutions show more potential for the proposed healthcare system than other IoT technologies which we used for comparison, and SigFox tops the table. Also WiFi solutions have shown significant potential. But again, every technology has its shortcomings as well. Further studies are needed to see if we can somehow make a hybrid healthcare system that utilizes multiple IoT technologies and incorporate the plus points of all of them into the system; such future system can prove to be revolutionary in the medical care.

Keywords: Situation Awareness, Internet of Things, Analytical Hierarchy Process

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

PREFACE

As part of a master's degree at Tampere University, we are required to complete a master's thesis. I chose to explore the potential of Internet of Things in situational awareness and took healthcare system as a use case. The work was done at Hervanta Campus of Tampere University. I finished it this summer.

I would like to thank my supervisors, Assoc. Prof. Elena-Simona Lohan and Dr. Jukka Talvitie for their supervision. My special thanks to Assoc. Prof. Elena-Simona Lohan for her continuous support throughout the project and all the time she spent on my better understanding on the concepts involved in the work.

I am also very grateful to my parents, my brother and my sisters for the continuous encouragement and support that I got from them in completing this work.

Tampere, 15 September 2019

Ali Zaheer

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ABC	Accelerated Bridge Construction
AHP	Analytic Hierarchy process
Ah	Ampere hour
ASCE	American Society of Civil Engineers
BLE	Bluetooth Low Energy
BPR	Business Process Reengineering
CBR	Case-Based reasoning
CI	Consistency Index
CR	Consistency Ratio
DSRC	Dedicated Short-Range Communication
D2D	Device-to-Device
DAG	Directional Acyclic Graph
FCE	Fuzzy Comprehensive Evaluation
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
Gbps	Gigabits per second
GSM	Global System for Mobile Communications
HTML	Hypertext Markup Language
HSA	Hierarchical Spatial Analysis
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IoTA	Internet of Things Agent object application
IPv4	Internet Protocol version 4

IPv6	Internet Protocol version 6
ISM Bands	Industrial, Scientific and Medical - radio bands
ISAHP	The International Symposium on the Analytic Hierarchy Process
Kbps	Kilobit per second
KBps	Kilobyte per second
LoRa	Long Range – An IoT Technology
LPWAN	Low Power Wide Area Network
LTE	Long-Term Evolution Fourth generation cellular network technology
mW	milli Watt
Mbps	Megabit per second
MBps	Megabyte per second
MIDAS	A building design and analysis solution
NASA	National Aeronautics and Space Administration
NB IoT	Narrowband Internet of Things
NFC	Near-Field Communication
QFD	Quality Function Deployment
RF4CE	Radio Frequency for Consumer Electronics.
RFID	Radio Frequency Identification Technology
RI	Random Index
RTLS	Real-time Locating System
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SoS	System of Systems
TQM	Total Quality Management
UMTS	Universal Mobile Teleommunication System

URL	Uniform Resource Locator
VRU	Vulnerable Road User
W-SIG	Weightless is a set of LPWAN open wireless technology standards by 'Special Interest Group'
WSN	Wireless Sensor Network
3G	Third generation cellular network technology
4G	Fourth generation cellular network technology
5G	Fifth generation cellular network technology

Symbols

w	Risks
A	Monitoring Ability
Λmax	Maximum Eigen value
n	Order of matrix

1. INTRODUCTION

Internet of Things have impacted almost every aspect of the society we are living in and many of the businesses around the world. We have tried to explore the potential of Internet of Things technologies for situational awareness and as a use case we have taken a healthcare system that would be used particularly by elderly people and the ones who are suffering from mental illness, dementia, for example. But we have also taken into consideration normal people who want to track and monitor their everyday activities to help them manage well and improve their quality of life and overall well-being.

There have been instances from the recent past where research was performed to see the usage of IoT technologies in the healthcare from a medical perspective, for example, [73] attempts to find out how healthcare sector can benefit from the IoT, takes a similar use case, however, the final results of this research paper show that traditional methods of treating dementia are still preferred over the ones incorporating the IoT technologies. Furthermore, [74] digs into the matter and shows the importance of IoT in the healthcare sector, but again, this paper also takes the medical perspective. We have decided to try and see from an engineering point of view how the healthcare sector can benefit from the IoT technologies and we will consider a number of technologies and see how each of those perform and finally select the best of those based on criteria which take a purely engineering standpoint unlike the ones used in [73] and [74] purely engineering.

We have included in the set of IoT technologies for this work some short range technologies and couple of those which are used to wide area communication. The followings are the technologies that we have considered for the proposed healthcare system: Radio Frequency Identification Technology (RFID), Near-Field Communications (NFC), Bluetooth Low Energy (BLE), EnOcean, WiFi, Zigbee, Weightless SIG, Sigfox, LTE, Long range (LoRa) and Narrowband Internet of Things (NB-IoT). We have compared these technologies with each other with respect to different criteria. Here are the criteria considered:

- **Effectiveness** of the IoT technology for the proposed healthcare system and it will be gauged by range, accuracy, latency and data rates that any particular IoT technology can offer.
- **Acceptability** of the IoT technology can be judged by its availability, the battery life it can offer for normal functioning of the system that incorporates this technology and the level of security and privacy that it gives to the person related data and the overall system.
- **Cost of the technology**: From the economic perspective, we will further divide the criteria into the actual cost of the technology integration into the system that will include the cost of equipment, infrastructure and related stuff.
- **Power consumption** of the technology; it directly affects the cost of the system.
- **Complexity level** that can be associated with a particular IoT technology.

After applying the analytic hierarchy process we will have a look at the results and analyze those. We will draw some conclusion and discuss what can be done in future regarding the work we have performed.

1.1 Thesis Objectives and Author’s contribution

The central aim of the thesis is to select the most appropriate IoT technology that a smart healthcare system would employ to have situational awareness (SA) of the elderly and the people who are neurologically challenged.

Since every IoT technology has its pros and cons, and the choice of a suitable technology depends among a number of factors on the application for which it is being used for. Our use case is a smart healthcare system that would focus particularly the neurologically challenged people, for that we will have to consider many different factors while making the choice of IoT technology, for that we will have to compare the chosen technologies with each other against different criteria, in order to ensure the highest possible prediction accuracy of the selected alternative, we need to rely on a big amount of experimental data. In most cases it is not feasible to have all those measurements as it will require a significant amount of effort and cost as well which may be out of scope of the project like the one we are working on. Consequently, we are taking the approach of research and have chosen the technologies and criteria for which there is a large number of research articles and related papers available on the basis of which we can get the required quantitative data in order to compare and pick the most appropriate IoT technology for the proposed healthcare system. This general objective of getting quantitative data and analyzing it in order to select the IoT technology that best suits proposed paradigm is served by four specific objectives which are accomplished through publications mentioned in the references' section.

Following table shows those specific objectives along with the original contribution of the author and corresponding chapter of the thesis as well.

Table 1Thesis Objectives, author's contribution and corresponding chapters

Objective	Author's contribution	Thesis Chapter
To identify and different concepts of different situational awareness models and learn how to develop SA through AHP	Application of hierarchical framework for situational awareness	2 and 3
To study the scope of IoT in the healthcare industry and identify the criteria against which IoT technology would be selected	Empirical analysis based on the results of [73] and [74] which take criteria from a medcial perspective and then relate those criteria with the ones used in the actual AHP model from an engineering standpoint.	4
To construct an AHP model for selecting the most suitable IoT technology for the proposed healthcare system	Evaluating the relative priorities of criteria based on the interviews from the previous section and IoT technologies based on quantitative data collected from research papers. Deductive and analytical analysis of the so formed AHP model.	5
To solve the so-formed hierarchy in order to get the final rankings	Writing a matlab code to solve all the matrices of criteria, sub-criteria and IoT technologies with respect to all the sub-criteria. And then finally the overall comparison of the IoT technologies to select the most suitable one.	5

1.2 Thesis Structure

The document is structured as the first chapter tells about our expectation from this work and enlists the steps we are going to take to achieve that. And then the subsequent chapters discuss in details the related topics of this thesis.

In the second chapter we start with defining situational awareness and then we identify different models to accomplish that. We have a look at situational awareness from the wireless communication and Internet of things perspective. Then finally we see how a layered framework of situational awareness work since that is the one we have chosen to use to solve the use case.

Third chapter is all about analytical hierarchy process, this is what we will employ to select the most suitable IoT technology for the proposed healthcare system. So we describe in details all the relevant aspects of its process, from its definition to how it is formed in different layers and how we evaluate each layer step by step. Formation of matrixes of all the criteria and available alternatives, pairwise comparisons, weight values and relative priorities are defined and explained in this chapters. We took some practical examples of AHP usage that helped better understand the topic and the application of it in chapter 5.

Chapter 4 focuses primarily on the usage of IoT in the medical sector, its functions in the field and how healthcare industry is benefiting from modern IoT technologies. We also have mentioned some problems that the healthcare sector is facing because of incorporating such technologies into their systems. And finally the actual problem or the use case and the related criteria and sub criteria against which we will be deciding which technology to select from the perspective of healthcare professionals are discussed. However, in the next chapters we have tried to relate those criteria with the ones we have used in actual problem and seen from engineering perspective.

In chapter 5, we actually solve the problem, starting with formation of the solution framework and then the AHP. This chapters gives brief description of each and every element of the AHP structure including all the criteria and the chosen IoT technologies. The whole process of application of the AHP is given in this chapter. All the comparison matrices are formed and weight values are given to their elements through analytic analysis. Relative priorities of the elements of comparison matrices are found using matlab. We have mentioned the consistency ratio of all the matrices in this chapter, and in the end final rankings are given and analyzed briefly.

Last chapter then concludes the work and matches our expectations with the results that we got in the end. We have also discussed briefly in this chapter what work in future can be done regarding the role of the Internet of things in the healthcare sector specially the hybrid systems making use of multiple IoT technologies.

2. SITUATIONAL AWARENESS

Situational awareness is the up-to-date knowledge about the elements of a specific environment with time and space being the most significant references. SA involves understanding the meaning of those elements, potential threats associated with those elements and their impact on the environment in near future after some of the variables – time for example – have changed and ability to perform necessary actions.

The term Situational Awareness might have gained popularity in recent times but its concept has been in use by military around the world for quite a long time. It is believed that this term was first used by the Douglas Aircraft Company during their research on next generation commercial aircraft.

However in technical literature the concept of situational awareness started to show up roughly around 1983. It was employed while telling the plus points of prototype touch screen navigation display [1].This term has also been used by the air force of the United States after they came back from the Vietnam and Korea wars.

Originally from aviation psychology, concept of situational awareness has from then onward been utilized in many social fields. It was first used in safety critical systems such as air traffic control, however, in recent times this theory is being attempted to be transferred to network defense which according to [61] is termed as cyber situational awareness which makes use of a number of technologies to improve data and attack visualization in order to help the protectors process the data with ease. The issue of security and safety concerns many different industries and will continue to impact even more in the future. As the definition of situational awareness given in the beginning says an organization having situational awareness has the ability to combat against the threats it encounter from many different elements of its environment [57]. It is of prime importance for organizations to take it from an information risk management perspective, and a specific organization should be well-placed to have an information risk management system which can effectively manage any given scenario which is potentially harmful.

It is pretty obvious that situational awareness has so many applications since it is of primary importance for not only organizations but individuals and teams of individuals as well for their functioning in any type of environment. And that is the reason behind the emergence of situational awareness concept in so many different types of environment and industries, and not being limited to aviation.

Situation awareness can directly influence our lives and make it better. As per its definition, if we are aware of our environment and the potential changes which may occur in near future and have ability to perform proactively, we can definitely make better decision and avoid unwanted situations. It particularly takes into account many different elements of an environment with respect to space or time, so when any of them has changed it tells its effect on the overall situation.

Our main focus is on understanding environments around elederly individuals in this work, but we note here that the concept of SA and models to achieve it can help the decision makers and make their work easier and more efficient in some seriously complex and dynamic fields which include power plant operations, ship navigation, air traffic control, aviation – the source of the term situation awareness – and crisis states like firefighting etc. Situation awareness is also being applied to some very basic and not so complex environments that directly influence a common person’s life. The use-case of a smart healthcare system is an example which shows that when there exist good situation awareness one tend to have more accurate information about a system like what elements affect its output and how that output impacts the overall environment. And if the consequences are known in advance it will lead to better decision making and implementation of the planning. One the other hand it has been observed that poor or not enough situation awareness has emerged as one of the basic sources of accidents that occur due to human error [7].

2.1 Models of situational awareness

Psychologists and human factor researchers have given numerous models over the time that describe situational awareness. Let’s have a look at a few of those. Situational awareness models can be categorized as descriptive and computational models.

According to [2] Dr. Mica Endsley gave a descriptive model for SA which is arguably the most popular of the models given during that time. SA was presented for a dynamic decision making environment that is fairly generic. In the model of [2] many different factors from the environment and individuals as well interact with each other. According to the model of [2] SA works as kind of a loop of perception, decision and action.

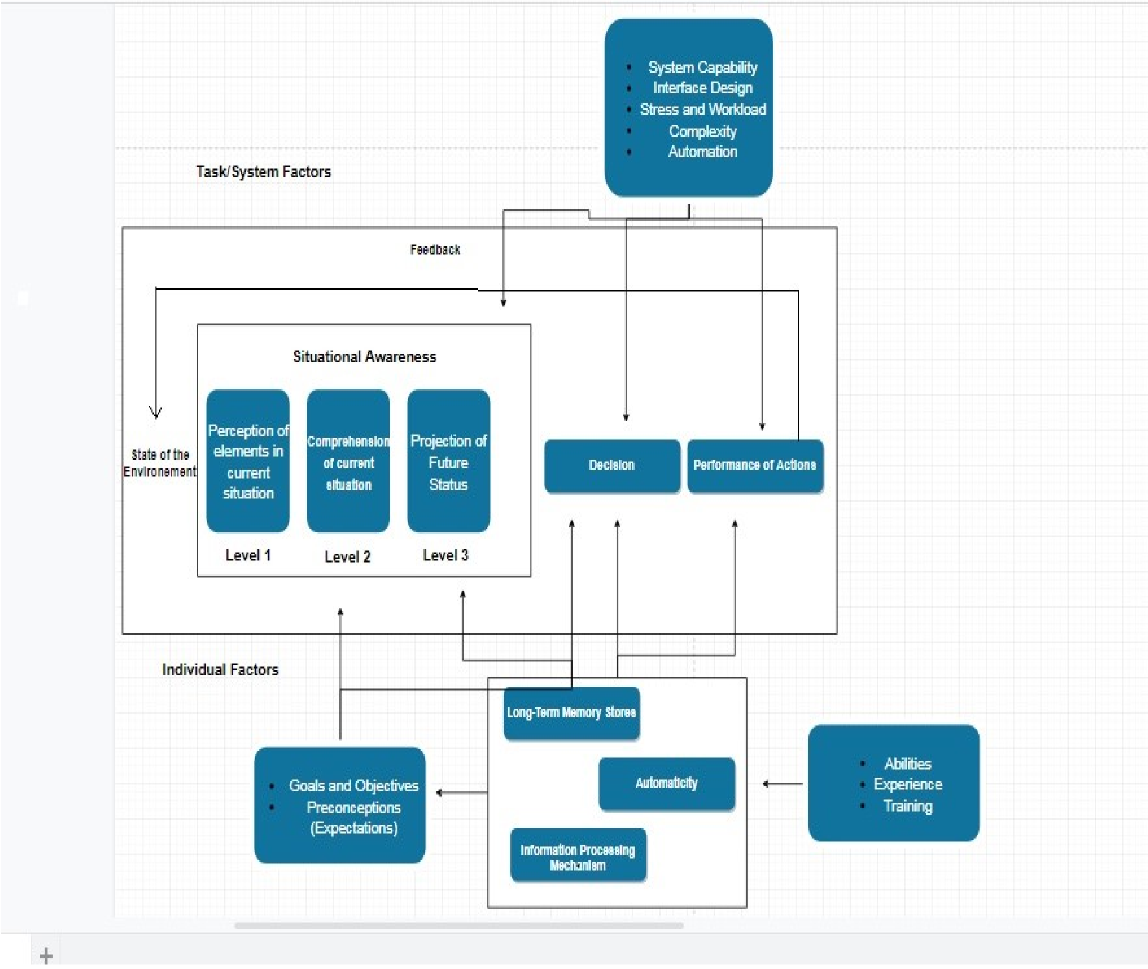

Figure 1 Endsley Model of Situational Awareness

.

Endsley's model considers a generic and dynamic environment for decision making. Figure 1 describes the model as a constituent of the perception-decision-action loop, and also depicts how a number of individual and environmental factors interact with each other. Attention and working memory are termed as critical factors as they limit effective SA. However, mental models can be formulated which along with goal-directed behavior can combat these limitations pretty well [2].

Descriptive models are considerably useful, however, there are some limitations as well. They can tackle some very fundamental problems which are encountered in situational awareness of some difficult and dynamic environments but when things get deeper and the comprehension of different scenarios based on many environmental elements and human factors come into place, and then decisions based on this are made, these models are not the reliable solution.

All the steps mentioned above require quantitative simulation of the whole process and so far we have not seen any of the descriptive models turning into kind of a model that supports this. There have been many computational models given for situational awareness. These models are aimed at providing better emulation of human behavior of decision making.

Since computational models are the solution for human decision making and situational awareness so the focus should be on developing such models that can represent or emulate human behavior. These are some generic models of situation awareness, we have used a multi-criteria decision making model for situation awarness for the use case that we have defined. Method is called analytic hierarchy process in which we derive ratio scales from pariwise comparisons of the elements invloved in the model. Input of AHP can be experimental data or can be subjective opinion. We have used both while applying the AHP. Minor inconsistencies are allowed in AHP and the consistency index is obtained from the maximum Eigen value. Principal Eigen vectors are used for getting the ratio scales. Details from the definition to the application process are given in the next chapter.

2.2 SA in the context of Wireless Communication and IoT

Now let’s see the concept of situational awareness in the context of wireless communication and modern day IoT.

Considering communication networks in general, at present, a new generation of wireless networks has been standardized; 5G, our objectives from it are to meet the ever-growing traffic demand, to be able to have considerably increased speed and shorter delays, this has enabled a tactile Internet. The latest generation of wireless networks also provides ultra-high reliability, and is able to connect a large number of different kinds of devices, for instance vehicles and sensors, to the Internet, to form an Internet of Things (IoT).

Cyberspace situational awareness

In [22] the concept of SA is presented as cyberspace situational awareness and the concept of cyberspace in the internet of things is not limited but extends from the Internet to the physical world between the objects and the personnel associated with them in one form or the other. The concept of cyber situational awareness is well elaborated by Barford et al [55]. According to that the whole idea of cyber situational awareness can be seen as 7 different ways. Here are those: [56]

- To know about a specific situation
- To know how accurate is the information about the situation
- To know about the effect and severity of an attack
- To know how different situations evolve
- To know the behavior of someone who causes the change in elements of an environment
- To know about the reasons causing a certain situation
- To know the changes which are likely to happen in the future

And the scope of cyberspace is advancing every day, but to get the desired results, there are certain things which are not helping, for example, risk factors and expected capabilities of the mechanism to process the data as quickly and with less effort as possible. According to [60] the so called defensive situational awareness mechanisms which are presently being applied are not good enough to deal with these roadblocks, so we need new and active situational awareness models which can enhance cyber situational awareness in this modern era where new developments take place every day [60].

Internet of things is ever developing, we currently have an enormous number of devices connected in it, and according to the analysts the number is going to swell even more; probably to tens of billions in years to follow. This will definitely help us in better decision making, since more number of devices are connected over the internet, more real time data can be communicated between those applications and devices and decision are made based on that real time data.

In IoT there are many different kinds of applications and devices are involved, so naturally the number of technologies being employed by the algorithms in advanced IoT are also in huge number, many of those can be compromised and makes way for an unauthorized access to sensors of somebody's smart phone. Before we move forward we need to know about sensor data. It is of great importance in the context of situation awareness in both IoT and wireless communication.

Wireless sensor networks and related issues

For all the communication between applications or devices that we are talking about we need to know the concept of wireless sensor networks, since these will be responsible for IoT operation. These are embedded networks, operate on considerably low bandwidth and also they use pretty low power.

Wireless Sensor Networks play a key role in the formation of a layered structure – described at the end of this chapter - for situational awareness. Their capability to track still and moving targets as well make them technology wise a good choice in the field of internet of things. There are a number of barriers that we encounter in employing wireless sensor networks in the internet of things and we do have technologies to get rid of most of those barriers.

There still remains an issue that we need to find ways to tackle with and that is energy problem. We have to deal with this issue to be able to use wireless sensor networks in the field of internet of things successfully. It is pretty interesting to note here that the very features that are responsible for making a wireless sensor network able to interact with the elements of a physical environment, data collection and supporting movability are the actual cause behind this long standing energy related problem. Because these components of the network are consuming their own power and not banking on the sources of the system since they have a built in battery. As the name 'wireless sensor network' tells devices are planted remotely and have to interact with each other and transmit data wirelessly, and this is the aspect of a wireless sensor network that consumes the most amount of power. So the way whole network is arranged dictates how much power the system as a whole is going to be consume.

Having mentioned that power consumption is of great importance, we have to keep in mind that in a layered structure that is arranged virtually the positions which the nodes are taking is very important as it will assess how power efficient the wireless sensor network has turned out to be.

At this point of time, it is quite rational assumption that in coming years we will have wireless sensor networks for which energy will not be a serious problem. However, wireless sensor networks have been employed quite extensively in the internet of things to help object applications, so we can set up a wireless sensor network as a layered topology virtually.

Sensor data

Sensor data is a vital element in IoT concepts, it is the output of a device that detects and responds to a specific change in physical environment. Wireless sensor networks (WSN) are a set of mobile embedded –implanted remotely – devices. There are some key points which are taken in consideration while designing them. Sensors should satisfy the following requirements:

- They should be small enough that they can be implanted physically close to the object which will be tracked and monitored.
- They have to be self-reliant, meaning that they should have an ability to work as a router and also a computer so that they can process the given data and then route it to its final destination.
- They should be conserving energy and use low power, they can conserve energy by using low data rate.
- They should be relying on each other to communicate the data over a distance to its final destination where the information obtained is finally extracted from the wireless sensor network.

For instance, for getting data of gyroscope and accelerometer, it is possible to do this without inciting the user about this, and then that data can be used to know any changes made in position or the speed of the person using that smart phone. Motion data does not remain difficult then to be known. It can be taken easily when either QR code is scanned, a URL is entered, or even an NFC card is tagged [57].

Near field communication (NFC) makes the phone pretty vulnerable to such insecurities. QR codes and NFC tags are well capable of activating and then getting the data of sensors. [57]. For example, no separate application is needed to be installed in a phone to get to its sensor data just by making use of HTML5 along with NFC. Because by doing so a web script is enabled and that does it all. So no separate application in the phone but just making use of a smart phone's web browser its security can be compromised.

We must note here that what is mentioned so far in this section as the source of vulnerabilities of smart phones; HTML5 along with NFC, are not something we can declare as flaws in smart phones designs or even we can't term it as a hacking strategy. It is nothing but an algorithm that uses the readymade or off-the-rack available features available in smart phones. So the questions arises how to avoid this kind of situation that compromises the security of a smart phone.

Smart phones or even other systems which are used for measurement and instrumentation that employ such technologies as NFC can cause some security issues, while using them their owners or users should be told the necessary security-related things needed to avoid unauthorized activation of sensors that eventually leads to access to the sensor data. They can do so by, for example, when the application is idle turn the NFC off or disable it. Users can also avoid such security concerns if they know about the URLs which open/close tabs in the browser. [21]

Situational awareness is kind of a technology framework that is employed to improve life safety, security, environmental monitoring and mass notification.

Cyber security

Cyber threats and cyber security have seen significant advancements over the years. For example, cyber security has enabled some mechanisms which let an entity be located geographically, furthermore, such mechanisms can interfere in almost any kind of electronic communication. Since they can intercept the normal functionality of smart devices, they can retrieve important and confidential data as well [59]. Password auditing has shown significant progress for protectors recently in terms of enhancing cyber situational awareness of them considering the capabilities of text-based authentication models which are employed by the companies. Protectors may include Information Technology or security professionals [58].So we can safely say that situation awareness is of primary importance in environments in which poor decision making can yield accidents or other serious consequences. Whether to share or not cyber situational awareness within and among organizations has to be seen from an information risk management perspective, and the organization must suitably be win a position to have an effective information risk management, to manage the consequences of information loss, occurring as a result of the sharing process. An effective situational awareness can help the organizations with this issue.

2.3 Examples of SA from real life

Smart Health

Let us suppose a heart monitoring system is installed in a home and one of its functions is to transmit the health information of the patient to a hospital over the Internet. The system will be transmitting the data in real time. The credibility of the information acquired about the condition of the patient would depend certainly upon the awareness of the physical and logical environment of the patients' home health monitoring system. Poor or no situational awareness of the patient's home can have very serious consequences. This paper will specifically focus on this field in the coming sections since the use case we will be solving in this paper is about the usage of internet of things technologies/devices for medical care. We will employ analytic hierarchy process to select the best available solution for some particular situation. We will discuss that in details in the later sections when we define the actual problem that we will be solving through AHP. Figure 2 gives some functions of IoT in the healthcare sector.

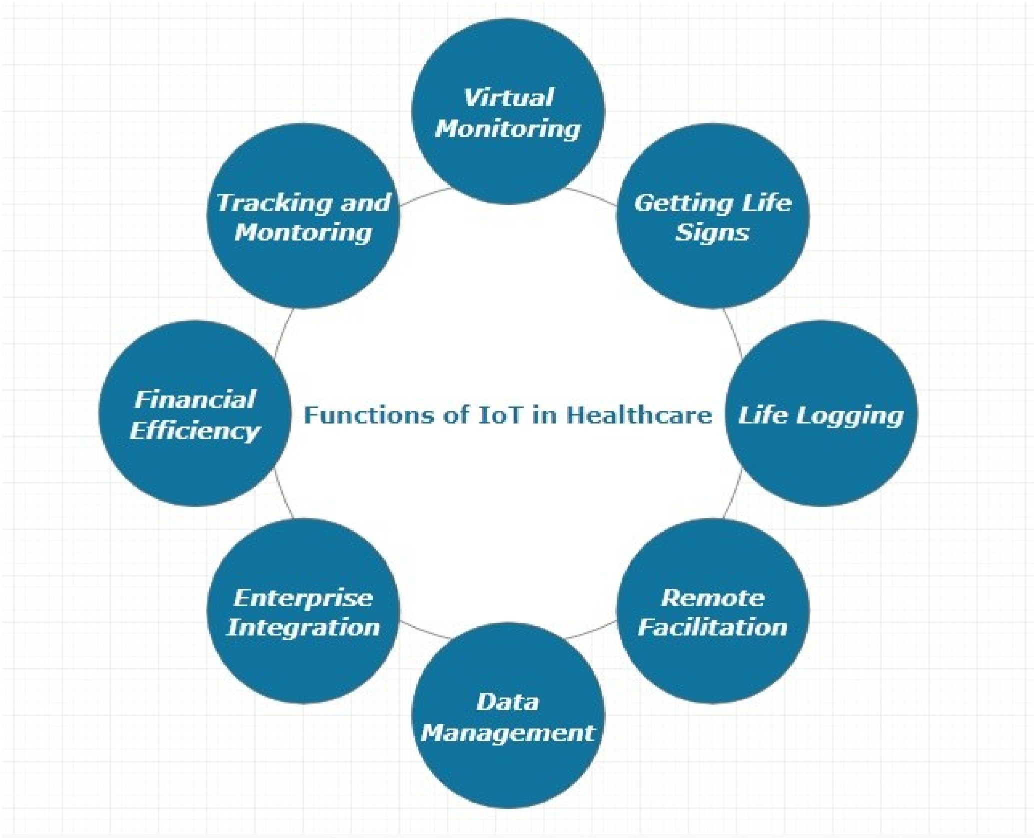

Figure 2 Functions of IoT in Healthcare Sector

Smart Mobility

Communication-based cooperative safety methods provide more accurate and extensive situational awareness in comparison with non-cooperative sensor-based methods. One of the biggest plus point associated with these kind of methods is that it enables both vehicle and vulnerable road user (VRU) to keep telling each other about their exact position and movement on regular intervals. This makes (GPS) global positioning system and other (GNSS) global navigation satellite systems important as the efficiency of communication based cooperative safety applications would depend on these navigation systems. [22]

Since obstructed VRU can't be timely detected by radars or cameras, so such systems can handle these situations well. A number of approaches that are based on wireless communication technologies have been proposed for communication based safety applications for VRUs. Wi-Fi Direct Cellular – Universal Mobile telecommunication System (UMTS), Long-term Evolution (LTE) – and Dedicated short range communication (DSRC) are seen to be the main options to solve the connectivity issue between VRU and vehicle. DSRC enabled devices tend to give omnidirectional and extended situational awareness range.

In smart transport there are systems that can differentiate between driving maneuvers which are different in terms of longitudinal or lateral movement patterns, it can predict the host vehicle – that incorporated the system - behavior, or any remote vehicle's trajectory as long as those are in the host vehicle's sensing or communication range. It ultimately enables the prediction of future maneuvers.

2.4 IoT protocols

As said earlier, there are a huge number of devices that are connected to each other and transmitting in real time, for better awareness of the situation we need them to continue their function, to have this considerably large data transmission pretty high bandwidth would be required but we would certainly want to minimize that need as much as possible. We would need some special technologies to work with in internet of things in order to tackle this bandwidth issue. We can make use of mist computing and data to decision D2D for this purpose. There are certainly more options available to handle this problem.

As discussed a little earlier they are designed in such a way to be relying on each other, it is done so since they do not work the way a typical phone network, ad-hoc or a wireless local area network – star topology – works. Wireless sensor network is data centric. Despite all these properties of WSNs, it was not long ago when we used to face three important issues in these kind of networks. They included the amount of data to be stored, internet was not compatible in WPAN, and moreover they didn't have enough space for IPv4 addresses. [23].These issues did not let the WSNs to be used for the IoT. To compensate for these shortcomings in WSN a state of the art technology has been used lately that solves the problems quite greatly. Here is what it offers, according to [23] to tackle the problems told above:

- It has cloud computing that has capability to accommodate enormous amount of data.
- In place of IPv4 it uses IPv6

- For the issue of internet incompatibility it employs 6LoWPAN; that is IPv6 over low power wireless personal area networks protocol.

2.5 Achieving situation awarerness

A number of approaches have thus far been employed for the measurement of human situational awareness. Situation Awareness Global Assessment Technique (SAGAT), for example is one of those; SAGAT according to [55] is a technology that is based on knowledge. In this approach the simulated mission has a role of human in it. This technique has been used quite extensively. One key feature is this method is that the simulation process become kind of suspended on various occasions just to let the operator respond to certain questions regarding various levels of situation awareness. Then in the following steps those answers which were given by the operator according to its findings are compared with the right ones which are known already. So this way they rely more on the knowledge that is already available. [24].

Out of many benefits of this technique one is that it is well capable of measuring the situation awareness in a direct manner, however, still we are not able to use this in real missions. The reason behind their inability to be used in real missions is the suspension in the course of work of the whole system that we just talked about. The system gets halted and the implementation of the mission is stopped at various points of time. The other reason is the knowledge about the correct answers. In order to use this approach we need to have the correct answers regarding different levels of situation awareness beforehand which we certainly can't have in real missions.

For the automation of a system we there need to look for other methods. Let's first define what automation means in general.

Automation

According to [24] "A technology that is capable of selecting data actively, transforming information, making decisions or controlling processes is called automation".

There can be different degrees to which we can say a system is automated and that degree of automation which we can associate with a system can be known by seeing the human role over the function of that particular system.

Autonomy is pretty relevant term here but a little different. It is the level of freedom in decision making that we give to a system. According to [24] autonomy is defined this way “the freedom in decision making subject to, and often in spite of, environmental constraints according to the internal laws and values that govern the agent”.

In order for us to have systems which are smart enough to have a balance in the role of human and devices, and can understand the dynamics of their interaction with each other, we need to give them flexible autonomy. In this context, autonomy is important for the proposed system, one of the features of the proposed healthcare system would be to take necessary actions in case of an emergency, and so the system should have such level of autonomy that it should not be relying on medical facilty staff to react to an emergency situation. But there can be situations where a specialist need to see the matter and then decide on the spot about the acitions to follow. So we just can’t ignore the human role in the proposed healthcare system.

So during the execution of a specific task in this kind of a system there can arise different degrees of autonomy. Depending upon who bring up the decision of altering the level of autonomy, there can be three different types of systems. These systems, according to [24] are termed as adaptable, adaptive and mixed initiative classes.

Adaptable Systems

These are deigned in such a way that human will be responsible for bringing up the suitable change in degree of autonomy while interacting with the other components of the system. However, some experts look at this as an extra burden on human side as they have to decide about the level of autonomy during the course of the execution of a mission. This added responsibility is seen as an extra load.

Adaptive Systems

In these kind of systems, as the name suggests, it is not a human but the automation that is responsible for taking those decisions, it does so by assessing the current state. In this way the added burden that was on human side in adaptable systems is handled by the automation.

However, this property is seen as a downside in this technique that the authorization power does not remain in the human hands but gets transferred to automation.

Mixed Initiative Systems

We see that both adaptable and adaptive systems have their pros and cons, we mix the plus points of both the techniques in the so called mixed-initiative systems. According to [23], these kind of systems enable decision making in which both human and automation contribute. Mixed-initiative systems incorporate both the techniques in a way that when there are some critical situations, adaptive part of the systems is triggered off. For the rest of the time the other one is working.

There exist a number of architectures that can be used for situational awareness but we will be focusing in this paper on the layered structure of situational awareness.

2.6 Layered structure of SA

As discussed in the first section of this paper that computational models are the ones that support quantitative simulations of the whole process of situational awareness. These systems see the situational awareness as an integrated inferential diagnostic process. And in the process, different situations are seen as speculated reasons, what happens in an environment – any change in the elements of the environment - and all the outputs that we get from the sensors – what they detect from the environment - are termed as the effects.

Level 1

The procedure of this system starts at the point where any change in the elements of the environment is occurred. And when the change is observed by the sensor installed in its vicinity, then their potential effects on the current state (situation) of the environment is assessed. They do so by diagnostic reasoning, which is kind of a back tracing of the event-situation relationship.

We have discussed in details in the first section that diagnostic reasoning is performed by Bayesian Belief systems.

Once the impact of changes on the current state of the environment is evaluated, the effect of the events which are likely to happen in the future is proposed. This is done by forward inference of the event-situation relationship and this technique is termed as inferential reasoning. For an illustration, have a look at figure 3.

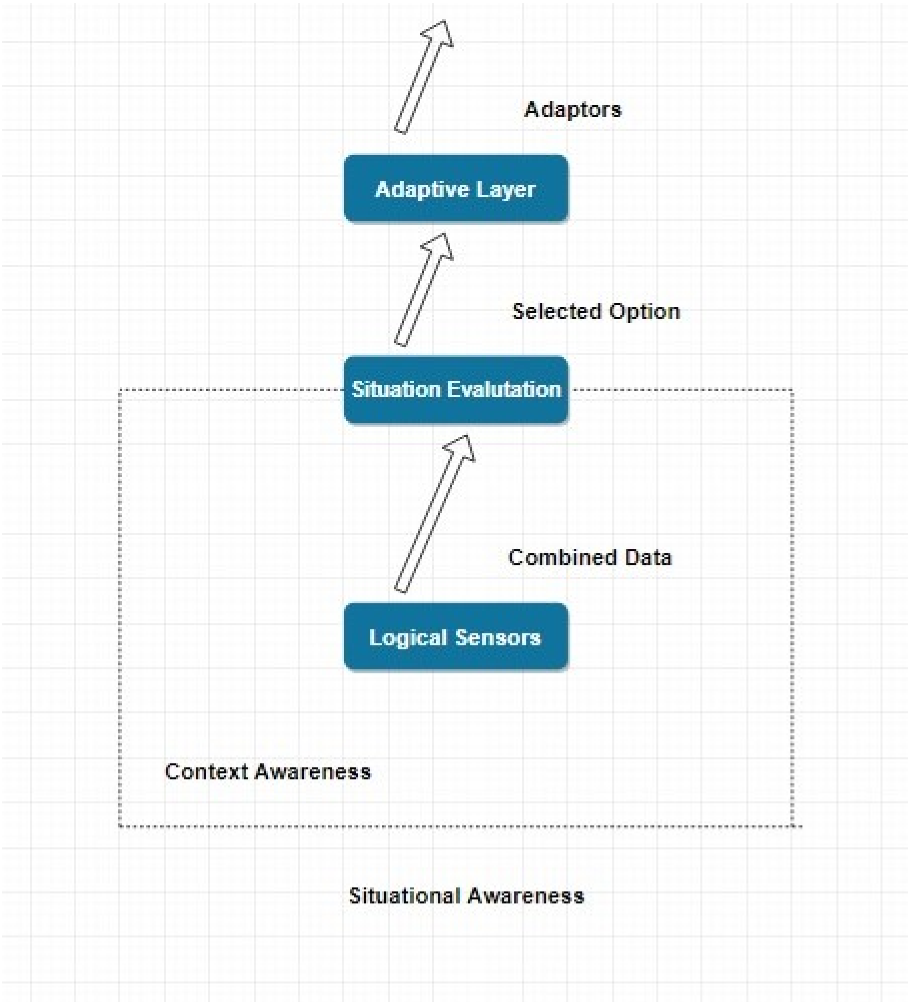

Figure 3 Layered Architecture of Situational Awareness

From the figure 3, we can see that situational awareness works at physical layer level. Logical sensors detect any changes occurring in the elements of the environment in their vicinity and the associated data is then transmitted to the base station. First level in the given architecture just informs the base about the current state of the environment.

Level 2

In the second level, the data about a specific situation that was acquired in first stage is comprehended. The base station considers a holistic perspective of the environment based on that information because this is phase where the base station should know what kind of changes the elements of the environment have gone through.

Level 3

Third level is the evaluation stage; the last one. Here the impact the environment would have in the future in response to the changes in the elements of the environment is projected. And in the second part of this stage the base station depending upon its comprehension of the current situation takes a final decision and start a suitable action as corrective measure.

3. ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process is one of the many methods being used for decision making, this is based on multiple criteria. This organized methodology is used for forming and analyzing decisions, and it has capability to deal with quite complex decisions, based on psychology and mathematics.

If we go in the history, this method was first developed in 1970s by Professor Thomas L. Saaty. [9]

However, there have been many studies conducted on this topic and it has evolved over the years and been used in a wide range of fields.

Something that really makes the analytic hierarchy process stands out among other decision making methods is that it does not focus primarily on giving ‘correct’ decisions, rather, the main objective of it is to help the decision makers find a solution that is most beneficial for their ultimate objective from a particular situation and the one that best conforms to their own understanding of the problem.

This technique gives an all-round model for organizing a situation that fully depict a decision problem. The model represents all the relevant elements involved in the process and link up those elements with the ultimate objectives of the decision makers. This method also considers alternatives and choose from those which are suitable for achieving final goal. ‘Alternatives’ are very important part of the structure of analytic hierarchy process, we will see that in the coming sections.

In other words analytic hierarchy process is a technique to obtain ratio scales out of paired comparisons. For this process, the input is taken from existent measurement; cost and weight for example. Inputs in this methodology can also be drawn out of subjective opinions like choice and the degree of satisfaction as well. Since human factor elements are vital in this kind of methodology and they are not perfect and consistent all the time so analytic hierarchy process takes this into account and can tolerate a little inconsistency in the decisions.

Two things that will be responsible for helping the decision makers for achieving their goals are ratio scales and consistency index. The first are obtained from the principal Eigen vectors and the second from the principal Eigen value.

3.1 Working Principle of AHP

The way analytic hierarchy process work can be broken down to four simple steps. Following is a brief description of each of those.

Formation of Hierarchy

In Analytic Hierarchy Process the first step is the breakdown of the original problem into kind of a hierarchy of sub problems which are not that much complex and can easily be understood and apprehended. The sub problems are not dependent to each other which means they can be treated separately and examined one by one. However, all parts of the hierarchical structure can pertain to any of the characteristics of the actual problem like both abstract and perceptible, a quantity that is calculated accurately or the one which is just a rough approximation, in short everything that can impact the final decision regarding the actual problem. This is the stage in hierarchical process where all the members of the team working on the problem dig into all the aspects of the core problem from generic to very specific and well detailed levels. And then arrange all of that in a layered structure which obviously is needed during the execution of analytic hierarchical process. The participants of the process with the passage of time and working more and more on the hierarchy building enhance their level of realization and understanding about the core problem. And also, they get to know about opinions of each other.

Definition of Hierarchy

It is a layered structure in which all elements are arranged in a set sequence, and the elements can be people or even their ideas and the hierarchy is used to organize those and rank as well. Barring the one sitting on the top of the structure, all of the elements are dependent; one depends on another or many others. Once the hierarchy is formed, its concept can be well understood in an intuitive manner, however, working towards the ultimate goal it is represented in a mathematical way. It is pretty common that diagrams of the layered structure are given in pyramid shape since one independent element is sitting on the top of the structure.

In the context of analytic hierarchical process that we are studying here as a decision taking methodology a hierarchy is a layered structure that is used to represent the mockup of a decision. The ultimate goal will be placed on top of the structure and the remaining elements include all available alternatives each of which can be potential way to achieve the final goal and all the criteria that can be considered for making the best choice from the available alternatives to get to the ultimate objective. It is possible to further divide the criteria into sub criteria – there can be multiple levels of it depending upon the complexity of the problem at hand. The need of sub criteria comes from the fact that some of these can't be applied in a uniform manner so they contain graded differences and in such cases they can be further split into sub criteria to show a level of intensity of a certain criterion, for example. And the required level is chosen on the basis of comparisons made under the actual criterion. In the literature when applications of analytic hierarchical process are given it is common to give with them their relevant diagrams and their details.

The shape that the hierarchy of this process will take depends upon many factors which include type and nature of the given problem. In addition to this, all the members of the team that is responsible for taking the final decision will have their input in the overall design on the hierarchy like opinions, information and assessments of each of the members will have its role in the overall design of the hierarchy.

Hierarchy Depiction

In order to make it clearer how hierarchies work in this layered decision making system we describe a generic example of a problem for which it is required to achieve a specific goal and have a look at the relevant diagram.

In this problem, we are required to get to a final goal and we have three different ways as options to go there, known as 'alternatives' from the previous sections. To decide which option to go for we have to evaluate those ways against three different criteria which are further having four sub-criteria. So we need to consider of all those in order to prioritize alternatives and choose the one that best suits the final goal.

Figure 4 illustrates that the main objective which is final goal is sitting at the top of the layered structure, then all the criteria and respective sub-criteria and at the very bottom all of the available alternatives.

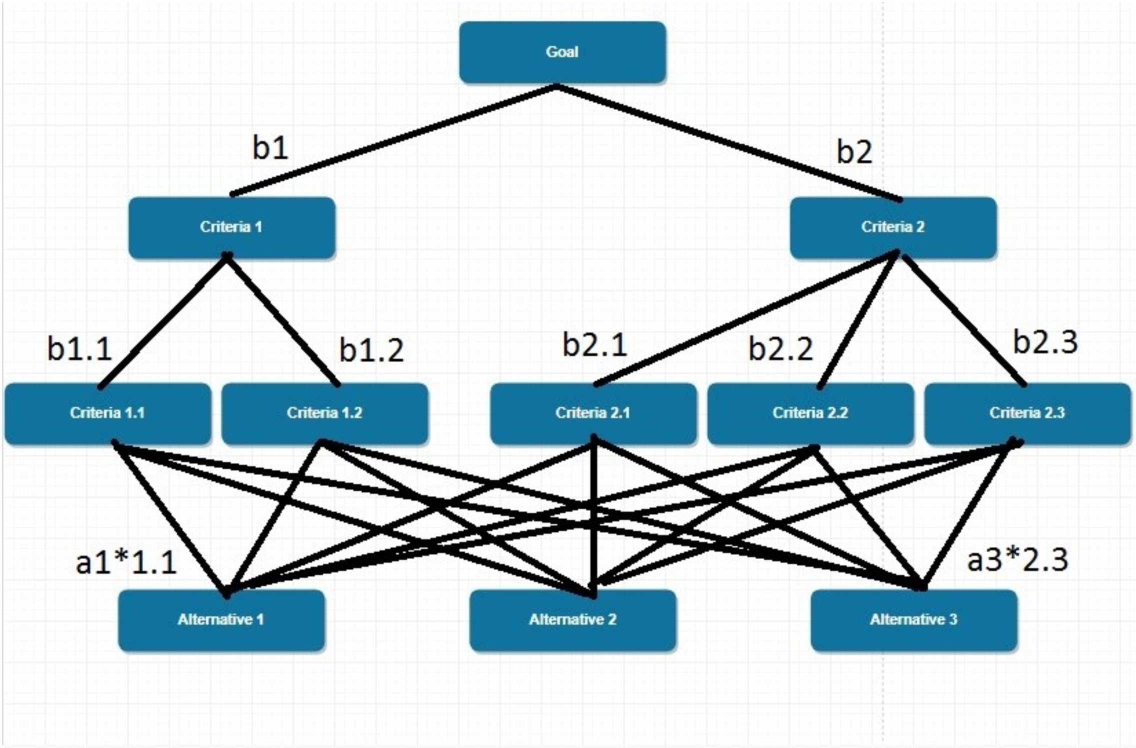

Figure 4 Simple Example of an Analytic Hierarchy Process framework

In the figure, b1 and b2 represent the weights of the main criteria, b1.1 and b1.2 represent the sub-criteria of main criteria 1. Similarly, b2.1, b2.2 and b2.3 are the weights of sub-criteria of the seconsmain criteria. At the lowest level, a1*1.1 and a3*2.3 are the weights of the alternatives with respect to the sub-criteria. Weights of the other alternatives are not shown for clarity reasons.

It is customary in literature to use the terms that we have used here for different sections of the hierarchy, for example, ‘goal’, ‘alternatives’, ‘criteria’ and ‘sub-criteria’. Furthermore, all the boxes are termed as ‘nodes’ and classified as parent and children nodes. The one linking up with the nodes in the level underneath it is called a parent node. The ones to which that parent node is joined with are termed as children nodes. Each node in the system is connected to at least one other node. The connection shows its relevance and dependence on the other one. In view of this, ‘goal’ is parent node for the underlying criteria nodes which in turn are called children of that top node. In a similar way, sub-criteria nodes are children and for those every of the criteria node is a parent. Same goes for the last level where alternatives are children and every of the sub-criteria node is a parent. We see that same children nodes are associated with different parent nodes at each level down the main goal which means that all the children nodes which include criteria, sub-criteria and alternatives are repeated and shown to be connecting with all the parent nodes which they are associated with. This repetition has some benefits. This way of arranging a hierarchy with every child from all the parents being represented with just a single node and the use of lines to show relevant connections between parent and children nodes definitely lowers the amount of complexity and the size of the overall structure of the system. However, these connecting lined may look a little scrambled as these can be more and more in number with the increase in number of alternatives and criteria. To get rid this of this jumble it is possible that the connecting lines are either taken out or lowered in count. But it is important to note here that irrespective of the changes that we just mentioned for lowering the complexity and size of the hierarchy and make it simpler, all of the criteria need to be linked up with relevant alternatives on an individual basis in the real hierarchy when it is being processed. For this reason, it is possible that the connecting lines are looked upon as they are heading down towards the children nodes leaving the parent node from a higher level to a lower one in the structure.

Evaluation of elements by comparison

In the next step after the hierarchical structure is formed, respective elements of the hierarchy are assessed by the decision makers in a consistent manner. They do it by making a comparison among each of those elements by taking two at once, the focus is on knowing the effect of an element on the element which is one step higher in the next level of the hierarchy. Each and every element of the hierarchy is pairwise compared with other elements as follow:

$$A = \begin{bmatrix} 1 & w1/w2 & w1/w3 & \dots & w1/wn \\ w2/w1 & 1 & w2/w3 & \dots & w2/wn \\ w3/w1 & w3/w2 & 1 & \dots & w3/wn \\ . & . & . & & . \\ . & . & . & . & . \\ . & . & . & . & . \\ wn/w1 & wn/w2 & wn/w3 & \dots & 1 \end{bmatrix} \quad (1)$$

Here *A* = Matrix for pairwise comparison
w1 = weight associated with element 1
w2 = weight associated with element 2
w3 = weight associated with element 3

wn = weight associated with element n

To find out the relative importance or prefernce of two elements of the hierarchy, a ratio scale given by Saaty is used. Details about that ratio scale are given in chapter 5.

An expert analysis involve a number of comparisons in pair which would draw for all the respective nodes several numerical standards of measurement. Since we have a number of criteria to consider while making a choice for the most suitable alternative to achieve the final goal so we take two at a time and compare criteria with respect to their importance for the final objective. Comparisons of available alternatives in pairs are made with respect to all of the criteria and in this provides the basis for evaluating which alternative has preference over the others and is the most suitable for achieving the final goal. All of these comparisons are made using mathematical functions. And what we get as a result of this procedure is the respective priority for all of the nodes at individual level.

If we look into the figure 4 again, one of the major things that participants of a layered decision making process need to do is to find out the right value of weight that they would associate with every of the criteria that will eventually dictate their decision about the final goal that they are working on. Furthermore, another important thing that the decision makers need to do is figure out a reasonable value of weight that they would associate with each of the available alternatives with respect to all the criteria at individual level. Analytic hierarchy process in addition to doing these important tasks helps the decision makers give an objective and substantive mathematical value to all those criteria.

While comparing the elements with each other, it is possible to use tangible data available about them at the moment but the decision makers generally do not do this and rely on their own opinions that they have made about the significance of those elements with respect to each other. We can see this as a specialty of this hierarchical process of decision making that we can use our own opinions and thoughts in assessing situations and making decisions about them and not relying just on the information available at hand at a particular moment.

Derivation of the 'weight' for elements

In the following step of the analytic hierarchical process the evaluations obtained from the comparisons between different elements are transformed into numerical values which can then be treated and analyzed for the whole range of the problem. All the elements are treated in a way that in the end we can associate a numerical value to each of those that tells about the priority that it would get over the other elements. The numerical value is called 'weight'. This is a way that lets us compare in a logical and consistent manner such elements with each other which are incomparable otherwise. This feature of analytic hierarchy process makes is stand out among other methodologies used for decision making. Method to calculate the relative weights of elements of all the matrices for pairwise comparison that we plan to use in this work is Eigenvalue method. The equation 2 illustrates the method.

$$(A - \lambda_{max} I)W = 0 \tag{2}$$

Here *W* = the relative weights of matrix *A*
λ_{max} = the greatest Eigenvalue of matrix A
I = unit matrix

Weights mentioned in the equation 1 are scaler quantities associated with the individual elements of the comparison matrix, here W represents a vector that comprises of relative weights of the pairwise comparison matrix A [102].

Prioritizing the alternatives

In the fourth and final step of this methodology, weight, in mathematical form, is derived for all the alternatives available for the final decision to know the relative priority of all of them. As discussed earlier the weight tells about the degree to which a specific element or alternative in this case can be beneficial for achieving the ultimate goal. So, the alternative which gets the best numerical value after the comparison is done is thought to have the capability out of all available options to best match the requirements for solving the actual problem and achieving the ultimate objective. The rest is pretty easy and straightforward for the decision makers as they know which course of action to follow [9].The relative weights of all the elements of the hierarchy are aggregated to get the overall rankings for the available options – IoT technologies in this work – as illustrated by equation 3.

$$Wi = \sum_{j=1}^{j=m} aij\, bj \qquad i = 1 \ldots\ldots n \tag{3}$$

Here $Wi =$ total weight of the alternative i
aij = weight of the alternative i with respect to criteria j
bj = weight of the criteria j
m = number of criteria
n= number of alternatives

Prioritizing the alternatives is a very important part of the analytic hierarchy process so let's discuss the priorities a little bit more in details.

Setting up Priorities

We first try and define the term priority in the context of a decision making process. This is a number that is given to the nodes available in the hierarchical structure of the decision making process. These numbers are used to express the weight of each of the corresponding nodes with respect to each other in a particular group.

Priorities resemble with probabilities in such a way that these too are absolute number, with no dimensions or units. These numbers has a range from 0 to 1. Let us suppose a node 'x' has a priority value of 0.300 and there is another node 'y' with a priority value 0.600, it would mean that 'y' carries double the weight as compared to 'x', in other words, 'x' is half favorable in achieving the final goal in comparison with 'y'. In this way, looking at the priority value we can tell about any node how favorable that would be for achieving the final goal. So weight is the thing that can be interpreted as anything – like preference or value or probability - that the participants of the AHP process would consider in solving the decision problem.

The way how hierarchical architecture was built defines how the priorities would be distributed across the entire structure. Weight values are derived from the data that is fed by the users of the AHP. The three key parts of this hierarchical decision making process – alternatives, criteria, and corresponding weight or priorities – are linked up with each other in a close manner but still need to be processed and analyzed at individual level. There are some important features of the AHP process that need to be kept in mind while the application of the method is in process. As per the definition and ideally the final objective has a priority of 1.000. Sum of the corresponding priorities of all the elements of the set of available alternatives will essentially be 1.000. Same is the case with criteria when the hierarchical structure includes just a single level of it, meaning that if there is just a single layer of criteria then the sum of corresponding priorities will be 1.000 but things get complex with the increasing number of levels – when there are more and more sub-criteria – just like the case illustrated in the figure.

To better understand the priorities in case there are more than one sub levels of criteria we consider an example. Say, there are two main criteria named as ‘A’ and ‘B’ for the final goal, their individual priorities can be anything but when added together would be 1.000. Suppose 0.5000 is the priority of each of the criteria. ‘A’ has four sub criteria named as a1, a2, a3 and a4 whereas sub criteria of ‘B are two in number and named as b1 and b2. All these 6 sub criteria can have any value of priority but essentially sub criteria of ‘A’ would add up to 0.5000 and same would be the case with sub criteria of ‘B’ they all would add up to 0.5000. We notice that priorities will have a sum equal to 1.000 on all the main levels of the hierarchy. Top tier that represent the final goal, lower tier that shows all the available alternatives and the one in the middle which presents all the criteria can have any value as their priority but essentially the total sum of the values of their elements would be equal to 1.000.

It is important to note here that all the nodes of alternatives and criteria levels will have their default values until information about their weights has been fed to the system. Default values of priorities are those which are equal in amount and given to the alternatives and criteria until the point the systems gets data about the weights of these levels. If we consider the example we were just discussing the two main criteria would have priorities of 0.5000 and each of the sub criteria of ‘A’ would have a priority value of 0.125 and sub criteria of ‘B’ would all have priority value of 0.250. So addition of more sub criteria would affect the priority value in such a way that it will then have to be adjusted to give a sum value equal to the priority value of the main criterion. Same would happen to the alternatives if the number is changed. For example, if this is increased from three to four, each of it would have lower priority value and the opposite would happen in case of decrease in number of alternatives. These all are termed as default priority values of the hierarchy.

However, it must be kept in mind while processing a hierarchy during the AHP application that these values depend upon the weights that we associate with each of the alternative and criterion so they will change as soon as the system gets information about those weights.

There are a couple of more things that we need to consider about criteria if there are multiple levels of criteria in a hierarchy; these are termed as global priorities and local priorities.

3.2 Types of Priorities

Local Priorities

These priorities consider the relative weights of all the sub criteria which come under a specific criterion - or sub criterion - with respect to that very criterion. For example, relative weights of a1, a2, a3 and a4 (siblings) with respect to ‘A’ (parent). These priorities should also have a sum equal to 1.000.

Global Priorities

To get global priorities, the product of local priorities of all the siblings of a particular group is taken with the global priority of their parent. The sum of all the sub criteria present in a particular level will be equal to 1.000. It does not matter if there are multiples groups, for one level, it would essentially add up to 1.000. Taking the same example again, a1, a2, a3, a4, b1 and b2 would add up to 1.000. Addition of more groups on the same level would have made no difference to the total sum.

With all this discussion about the priorities, their types and characteristics, the rule says the following:

If global priorities of child nodes are taken for a hierarchy, their sum would be equal to the parent’s global priority. And for all those child nodes, the sum of their local priorities would be equal to 1.000.

All the characteristics of priorities that we have defined in this section are for the default ones, as this hierarchical decision making process progresses, the participants of the process would need to alter these values of priorities because the significance of different nodes no longer remains same after information about them is fed to the system. In order to do this, a number of pairwise comparisons are made in order.

According to the experts of analytic hierarchy process, the best way to learn and understand the concept of the whole process is to apply the AHP to different use cases.

Fuzzy Comprehensive Evaluation

Normally the technique used in analytic hierarchy process is pretty subjective when it comes to deciding about the index importance allocation. So in order to have more logical and fair index weights the concept is sometimes compounded with that of fuzzy mathematics. [25]

Fuzzy mathematics is about fuzzy sets which differ from the regular sets in a way that in normal set theory we only have two things to tell about a specific element; it does belong to a particular set or it doesn't – it is decided in binary terms keeping in view a bivalent condition – and we are not sure in fuzzy sets whether an element does belong to it or not. This is the reason why fuzzy sets are sometimes also termed as uncertain sets. Whether an element is a member of a particular set or not we are allowed in this kind of set theory to assess gradually and this is depicted with the help of a membership function which is evaluated in real unit interval [0, 1]. [8]

Fuzzy mathematics has been used in a variety of areas especially in the ones that have incomplete or inaccurate data. Bioinformatics, for instance.

Fuzzy Comprehensive Evaluation (FCE) which is kind of a mathematical way to thoroughly figuring things out which are found a little hard to be specified in a clear manner with the help of fuzzy set theory. Since there are many different alternatives under consideration to choose from for all the available criteria to get to the final goal in an analytic hierarchy process as it is depicted in figure 4 it is very important to prioritize those alternatives, and this is accomplished by making use of this technique; fuzzy comprehensive evaluation. And this information work as a reference in decision making for the decision makers. In situational awareness related literature there are a number of references arguing that fuzzy comprehensive evaluation can be used in conjunction with analytic hierarchy process in order to achieve an all-round situational value. [25]

3.3 Criticism of AHP

Analytic hierarchy process has been an important subject in higher education and is part of many courses at university level. It has become a part of a large number of management science related text books and also operations research. Institute of Operations Research and the Management Sciences which is a major society for operations research have officially acknowledged extensive influence of analytic hierarchy process on its fields. [10]

Organization which have worked specifically on theoretical justification of analytic hierarchy process at different levels use it quite extensively. There is found to be a general unanimity about analytic hierarchy process that it is logical and technically sound and at the same time practically effective, still there are critics of the AHP process. In [10], a number of examples are given where publications address the topic of the hierarchical process in details and the criticism of it, from those publications, one says that in all the domains of criteria based decision making methods when it comes to number of publications, analytic hierarchy process tops the table.

In spite of tremendous number of publications in favor of AHP process, we still get to see occasional criticism of this method. Here are a couple of examples:

One publication, according to [9] assert that unobjectionable and innoxious changes made in the hierarchy or the overall model of the AHP can sometimes bring in order which would not have existed otherwise. Another publication from the same source claims that if hierarchy is changed in such a way that new criteria are introduced in the structure and for those criteria all the alternatives do evenly this situation can result into changed priorities of the alternatives.

Before we move further let us know about an important phenomenon in analytic hierarchy process and that is ‘Rank Reversal’.

3.4 Rank Reversal

In all kind of strategies used for decision making it is essential that alternatives in hand would be ranked and put in order on the basis of criteria involved or the characteristics associated with alternatives. It is believed for many decision making methods that order in which the alternatives are put based on their preferability for the final goal must not change, even if new options are introduced to the system or the way options are chosen changes, it should not change. That change in the order would be termed as rank reversal.

However, there also exist a school of thought that believes even if new options are introduced to the main problem as alternatives they would not do rank reversal as long as they do not bring any additional characters. It should be noted here that there can be situations where a little bit of rank reversal is expected and interestingly it was taken into account and permitted when the analytic hierarchy process was formed originally.

According to [9] Forman, presented a new mode of synthesis for analytic hierarchy process in the early 1990s that made sure no change would occur in the order and rank of the alternatives which are already part of the main problem after any 'irrelevant' ones are introduced to the system or deleted from it. This synthesis mode is termed as 'ideal synthesis mode'.

So we see from this that there can be two types of analytic hierarchy process; one that accepts rank reversal and the other does not. The former is called 'distributive' and the latter 'ideal'. The version that is employed now a days for AHP process can conform to both of these. It incorporates both 'ideal' – to uphold the order or rank of alternatives - and 'distributive' – to permit changes in the order or rank of the alternatives – modes. And the selection of the mode is decided looking at the requirements of the main problem.

Figure 4 is a very simple illustration of the working principle of analytic hierarchy process.

Having looked into the working principle it is fairly obvious that applying this process would include a mathematical synthesis of a good number of assessments or evaluations concerning the core problem which is being processed. The number can be very large, probably it goes to several hundred sometimes. For the execution of mathematical functions calculators can be used, we can solve math simply by hand as well. However, the most usual approach to handle this synthesis process of decisions is to utilize computerized applications which can range from an ordinary spreadsheet program – for the easiest of the problems – to specially built software, depending on the problem involved – this is the case when core problems are rather complicated – these software are used in conjunction with special kind of instruments to get the assessments and opinions of the decision makers who all are part of the team working on a particular project.

Looking at the figure 4, we can understand that it is very much a straightforward options for persons looking for decisions in fairly simple situations, but it is rather more useful when it comes to groups of people working in difficult and complex situations and problems there are hard to solve. And in those situations where even if the problem is not too complex but the relevant stakes are high and the decisions are essentially dependent on human assessments and perceptions and those decisions have long-run significance and consequences that can impact the lives of other persons and the society as a whole.

One other benefit that we do not find in any other decision making methodology is the AHP method's capability to include in the comparison and computing process those elements which are different in nature and incomparable to each other but very important for achieving the final goal. Another situation where analytic hierarchy process has proved to be beneficial is when communication between the members of the decision making team is slowed down or even blocked due to difference in views or even nomenclature. [9]

3.5 Uses of Analytic Hierarchy Process

It has been employed in a number of fields for decision making purposes. It has capability to go a long way in tackling with the security issues in networks and yield great situational assessment taking into consideration many different factors. Here are a few of the situations where analytic hierarchy process can be applied for decision making.

Making a choice: As the definition of this decision making methodology says and also illustration shows that this technique works on comparisons and chooses the best alternative from a set of many different ones based on one or multiple criteria.

Prioritizing the alternatives: Before making one final choice it is possible to just find the worth of all the available alternatives with respect to each other.

Grading of the alternatives: Just processing the previous situation a little more; after the relative value of all the alternatives has been found, it is possible to rank them all in a decreasing order of their worth. The one at top being the best available option.

Distribution of resources: With analytic hierarchy process we can distribute the available pool of resources among different alternatives which are available at a time.

Standardization: Using this methodology an organization can evaluate their own operations by making a comparison of those with the ones believed to be a reference; probably from other organizations.

Managing the quality: Since this methodology is particularly useful when dealing with multiple elements of a process or phenomenon so it can effectively handle different aspects of quality and hence resulting in improved quality.

Conflict Resolution: There can be situations where objectives seem different and incompatible with each other among individuals or group of people, analytic hierarchy process can resolve these kind of issues.

In addition to these ones there are many more. It gets numerous when it comes to the number of applications in which analytic hierarchy process has helped in quite complicated situations for decision making; probably several thousand [9]. And the method has given comprehensive results in situations where the emphasis is on setting the priorities and choosing the best option out of all the available ones. Fields like Total Quality Management (TQM), Quality Function Deployment (QFD), and Business Process Reengineering (BPR) are among those which also have benefited from analytic hierarchy process. [9]

Practical Examples of the use of AHP

There are a number of applications that employ analytic hierarchy process but do not show up on main stream media, those are just not reported, reason being the security concerns of the big companies that use this process, and the usages is at such high levels that they do not reveal the relevant information in order to meet the privacy requirements. Still, some of the examples can be found in [10] where many big companies and universities from a number of countries including the US, UK and Germany have used and benifited from AHP. Examples include some occasions where this methodology is employed for making some special processes which are meant to be handling some very specific scenarios.

3.6 AHP for effectiveness of SA

Analytic hierarchy process improves the efficaciousness of the situational awareness immensely. For the incorporation of system of systems (SoS) information into shared situation awareness data it requires quite a complex interaction among a number of sensors, network structure and the degree to which it can be altered for better usage. In order to attain a superior level of situation awareness and a system that can proactively respond to any given situation it is required to have a robust and interoperable environment. [26]

To have an idea about the extent to which an integration of systems of systems and shared situational awareness can be effective we need to take account some knowledge based elements – cognitive elements – in addition to technological elements. This can be achieved by making use of the analytic hierarchy process.

There is no doubt that technological factors are important requirement in order to get enabled capabilities like data development, transmission and distribution of information for improved decision making.

While assessing technology related abilities, the things to take into account are the service that is responsible for data transmission through the network and the physical system as well. But this is not enough if we are looking to know the effectiveness of the mixture of a systems-of-systems and shared situation awareness. A thorough assessment of this can’t be completed by considering technological factors only. Since technology cannot function in separation so it should interact with human elements of the environment. Human factors that we talked about in previous sections have to be assessed along with the functionality of the service which is responsible for data transmission and the sensors themselves which are source of that data.

As said earlier that this integration of systems-of-systems concept with situation awareness will be based on analytic hierarchy process. Let us have a look briefly how the hierarchical evaluation process would work.

The foremost stage in this kind of hierarchical technique is the acquisition of necessary factors or elements from the disintegration of the main goal requirements. All in all the evaluation process would essentially include both technical and human factor elements as we just described these are complementary to each other.

a) Technical Elements

These elements are scenario dependent. And these are used to evaluate what the physical system has to offer; its capabilities.

b) Human Factor Elements

The role of human factor elements in the evaluation process include focusing on the way the user is looking at the systems-of-systems concept's ability to facilitate situation awareness. This knowledge-based evaluation process can be further classified into two types of elements; hard and soft elements. The hard ones are related to a user's perception about the attributes of the data that they obtain from the systems for example how much that was, how late it arrived, how complete it was, and of course the overall quality of this data as well.

On the other hand, soft elements are more relevant to meta-cognitive characteristics of the whole procedure of decision making. How trustworthy is the whole system and whether it can fulfill the requirements related to the information that would help in achieving desired level of situational awareness and decision making in perception of the user will be assessed by this part of the evaluation process.

c) Aggregation Process

And finally, a kind of assembling technique in which criteria are mixed with MOPs is used in order to evaluate the systems-of-systems. This is called aggregation process. Metrics are taken in sets from both of them and grouped together. Then taking into account different factors they are compared. And this comparison is based on a multi-decision criteria procedure just the way analytic hierarchy process work. The output that is obtained from this process tells about the extent to which a systems-of-systems concept can help situation process in better decision making.

So we see that both technical and human factor elements are required to be considered in order to evaluate the whole process of integrating the systems-of-systems concept and situational awareness based on an analytic hierarchy process for better decision making. However, to assess the significance of each of those in the overall process can be determined by looking at the context in which the systems-of-systems concept is being evaluated. [26]

And we see that each of the technology and human factor criteria is having a check on the quality control of the other to make the whole evaluation process more accurate. So we get better results if we consider both the criteria rather than using only one of those.

After having a detailed analysis of situational awareness and the models we can use to measure and evaluate it, especially the analytic hierarchy process, let us now move on to the definition of the problem that we will be solving through the application of concepts that we have learnt in the previous sections.

4. USAGE OF IOT TECHNOLOGY IN MEDICAL CARE

The internet of things have given us so many benefits and hence becoming a very important part of our everyday life. Ever increasing technologies of IoT is enabling more and more applications and services that it can accommodate, healthcare is one of those. This paper describes how medical care is benefitting from the usage of IoT technologies and devices. This chapter defines the use-case and describes some of the key IoT-enabled systems currently being used in the healthcare sector. These systems will ultimately be using the IoT technology that we select through the AHP in the next chapter. Having the proposed healthcare system in view, some basic criteria are given in this chapter from the viewpoint of the end user that can be taken into account in order to choose an IoT-enabled system. Functions of IoT and some issues associated with IoT in the heathcare sector are also discussed in this chapter.

4.1 Problem Definition:

This paper proposes a healthcare system that can be used by regular individuals for their well-being and improving their overall health-related conditions, the proposed system focuses primarily the elderly people, and the ones neurologically challenged. Some key functions of the system include tracking and monitoring of the individuals, remote assistance. The proposed systems takes into account a number of IoT technologies and based upon different criteria and relevant sub-criteria chooses the best option.Our task is to compare in a consistent manner the chosen IoT technologies based on those criteria and select the best one. Analytic hierarchy process is used to make the best possible decision.

Before we go into the details of the steps involved in the whole process, we have a look at how IoT is related to and benefitting the medical care.

With exponentially growing number of services that can be used in medical care, this field has observed revolutionary advancements in it over the recent years. Many of the modern IoT technologies which have been used in the medical field have resulted into improved and better medical services.

4.2 Functions of IoT in medical sector

Here are a few of the functions that Internet of Things devices and technologies have in medical sector.

Virtual Monitoring

We see that doctors can save a lot of their time that they spend in continuous monitoring of the situation of their patients in and out of their clinics/hospitals if they can make use of the virtualization concept. It is of even more importance if they have to deal with a number of patients. In virtualization, doctors have a facility to observe their patients even without having them to visit the clinic/hospital. They will interact with 2-way communication devices including good quality cameras. This way they can monitor their patients and give them the necessary consultation as well. Such systems can also be installed in hospitals where there is other staff with the doctor and multiple patients can be treated this way. These kind of virtual monitoring systems are specifically important for patients in emergency situations.

Getting information about life signs:

From life signs we mean some very basic readings that physicians take when we visit them. For example temperature, respiration, blood pressure, heart rate. There are instruments which get and keep these readings. Instruments are smart and they can do it continuously or at specific set times.

Getting information about some particular parameters which are related to chronic disease:

In the similar way as in the previous one, readings of some parameters which are essentially linked with some chronic disease are taken. Again, the instruments are smart and can keep taking the readings and store them continuously or at specific set occasions. These readings include stress levels, blood sugar, risk of seizure, water level, fat percentage in the blood etc.

From a user's perspective:

A smart system can combine the readings that were taken in previous two sections - life signs and about the parameters of some common chronic disease - for a regular person, compare those with the ones known as threshold levels, and if it finds any significant difference it can mention about this difference in the profile page of the person involved. Also, the system can prompt the person about some preinstalled precautionary actions.

Detectors and sensors for observation:

Patients and even the healthcare equipment they are carrying can be tracked and monitored courtesy of the IoT technology that make them able to connect and interact with the control centers which may be located anywhere. In this modern age, healthcare sector is employing a pretty useful IoT device which helps in fall detection of the people carrying those devices. Wearable have the sensors which have a record of the motion of the patient. These devices have a connecting system which establishes a connection of them with the control center that can be a hospital or any other medical facility so in case of an emergency it can directly and promptly send a message to the staff available at that medical facility and they can then attend to the patient without a delay. However, it has been pretty normal for the medical facilities to have kind of a panic button close the bed of the patient which when needed the patient can use to alarm the personnel there of its needs, with such IoT technologies it will be possible for the medical staff to be alerted about the patient situation wherever they are and that too without a delay. Even the system can be modified in such a way that when there is an emergency situation it will be able to respond to the situation automatically [11]

ID armbands or other such things are now a days being used for the track and monitor function using IoT. These are especially important when the infants are to be monitored in a medical facility. IoT supported ID is put on the baby and the mother, it will connect them with the control system. So inside a specific range all the activities and motion of the baby and mother will be in check. Same kind of labels can be used for the staff members, for example to confirm their presence and to know about the exact place of their presence, so in case of an emergency nearest available member from the hospital staff is alarmed about that.

So patients are not carrying any medical devices or equipment separately, they are just wearing their normal accessories and still being tracked and monitored by their doctors about every of their relevant movement and activity.

Life logging

A life log is a process in which individuals keep sort of a track for a number of reasons and purposes of their life in different amount of detail. That digital data fully comprises of their daily life activities. It is then possible to exploit and reinforce that data to have an insight of how that individual is living its life. Devices which are commonly used for this purpose are most of the times mobile and wearable accessories. [15]

A term closely related to life logging is called life caching in which the individual who keeps a record of its daily normal life events and activities share this with other people on some kind of open platform. This is kind of a social networking. And it is pretty obvious that such things are never without privacy related risks. There are available life logging apps and for which we have global positioning system (GPS), motion processors of different digital devices to make the work of capturing daily life activities easy.

Remote facilitation:

Medical care and related services to the patient can be given even when the doctor is not around. For example with the help of internet-optimized equipment, social health web, first aid, diet and medication administration. And the doctors can examine them remotely.

Use of RFID technology

Radio Frequency Identification Technology has been used in the IoT. Tags are mounted over the object which enables it to be tracked and monitored. Tags can carry useful information. RFID is mainly used for identification purposes. There are types of tags; active and passive. One having its own power source and the other relying on the closely located RFID reader. These are pretty useful in a sense that they can work even at distance of hundreds of meter from the reader and not needing a line of sight between the object and the reader. These tags can be mounted over many different types of objects. So at a medical facility a number of objects which are needed by a patient can be tracked and closest can be found when needed.

Data management

IoT can help medical sector at global level. For example at a health center there is available the complete collection of data related to a specific case; diagnosis, analysis, treatment, medicine, support, funding, supervision and everything. Having connected this with IoT at global level can be used and benefitted from by many health centers around the globe. That detailed report can be regenerated anywhere and anytime with respect to disease, patient, place, time and doctor as well. [11]

Centralization of an organization

IoT can help make the data of some particular patient available for everybody from the staff anytime and anywhere. For example, if IoT is incorporated within a medical care facility, interdepartmental data can be shared and is available anytime and anywhere for authorized members of the staff.

Having looked at some of the functions that IoT plays in the medical care sector, we must see that there are advantages and related problems of incorporating IoT in this field. We have a look at some of the advantages before we discuss problems associated with the IoT usage in the healthcare.

4.3 Advantages of IoT in medical care

Not limited to these ones, but here are some important benefits that we get from integration of the IoT in the medical sector.

Financial Efficiency

As we saw in the functions of IoT in the healthcare section that IoT enables a doctor to see, diagnose and treat a patient while being far, it saves quite some money that the patient might have spent in their visit to the doctor’s place. In addition to that there are equipment which let a patient treat the disease staying at their home, they don’t even need to visit a clinic or hospital. Patients can be tracked and monitored and eventually treated for their disease while staying at their home, it clearly reduces the cost of the treatment since they save the hospital expenses.

Errorless Information

We just discussed that most of the data collected in IoT integrated healthcare systems is automatic, it is free from human errors and quite accurate. So it the chances of medical errors are decreased greatly. Cost that is linked with such errors can be pretty high so we save that with the usage of IoT technologies in the medical care systems.

Better results

As the IoT integrated healthcare equipment is with the patient all the time, so the tracking and monitoring is seamless, all the relevant parameters are being read and measured continuously and automatically, the information is errorless and being stored and delivered to the staff of the medical facility without a delay and at set times. It is good even from the perspective of the management of the problem as the healthcare system that takes the readings of the disease related parameters reports about any abnormalities without a delay so it helps the doctor to respond and the attend to the patient in time before the problem progresses. So every part of the treatment is pretty smooth and happens in time.

From a patient's perspective

We see that IoT integrated medical care systems do a lot that results into contentment and the fulfillment of the patient's expectations. Everything gets done on time, treatment is seamless and consistent, all the readings of the relevant parameters are errorless and precise, patient getting everything while staying at home, no need to visit the medical care facility, IoT incorporation in the healthcare system ensures that the patient doesn't take extra amount of any drug or medicine and it does good to the hospital or medical care center as well as they prevent medicine wastage this way and it all saves them a good amount of money. So everything that IoT technologies bring to the system is impacting the patient in a good way.

Let us now have a look at some of the problems that are associated with the usage if IoT in medical sector.

4.4 Problems of IoT and healthcare systems

IoT integrated healthcare systems including accessories and other equipment remain most of the time with them and keep tracking and monitoring them, they are constantly getting information about them and sending it over the cloud. So these technologies are closely linked with the patient's privacy and more importantly health. And also with their routine life activities. Since these technologies are linked with their life so they can understandably affect them as well. So these aspects should be taken care of while designing, manufacturing and integration of the IoT in the healthcare systems and devices.

Let's have a look at some of the problems associated with the IoT integrated healthcare systems one by one.

Privacy

There have been instances of cyber-attacks on medical sector lately, integration of IoT technologies and being continuously connected of the healthcare systems and devices with the internet have made it prone to cyber-attacks. So this way the confidential data of patients is at risk of being stolen. It can result into privacy of the users of the IoT medical systems and also the financial loss to the organizations making use of those healthcare systems. Some ransom related incidents have also been reported for the hospitals in the United States. [13]. As we have seen from the previous sections that medical facilities are using more and more IoT integrated healthcare devices which are continuously connected and sending important information over the internet and the networks of those medical facilities can show some weaknesses which criminals can exploit and this way the information security is compromised. So it is of great importance for the health centers and hospitals to have networks which are safe enough, this will ensure the right use of the IoT technologies in the medical care devices and accessories. And safety of the patient is also ensured if the information about the patient is kept from the unauthorized persons, for example, some medical devices or accessories which a patient is carrying is responsible for some specific activity that is directly connected to patient's treatment or overall health and an unauthorized person gets access to such function then there are chances that it gets misused and will directly affect the health and even life of the patient adversely. Hence it is of utmost importance that the connections and the overall network in the IoT incorporated healthcare systems are secure and not vulnerable to cyber-attacks. But it is not an easy task to do by any means since those devices run together with the internet. So, information security needs to be assured by the designers and manufacturer of these systems.

Uninterrupted connectivity

Since the major function of the IoT integrated medical care systems and devices is their ability to keep it connected with the healthcare facility, so a faultless and secure internet connection needs to be present all the time and everywhere where IoT integrated healthcare systems are being used. It is very likely that medical care facility like clinics, hospitals and health centers do have internet connections but the patient who is using that healthcare system or accessory may well be without an internet connection at some time and this will can halt the process of consistent tracking and monitoring of the patient.

Round-the-clock Maintenance

IoT enabled medical care systems need to be working all the time without any kind of interruption because that's the way the system will ensure the timely and consistent communication of important information about the patient with the medical care facility and its staff. So the health center's staff responsible for taking care of the IoT integrated healthcare devices need to be available to give the required support to the system all the day and every day. Because their inability to give this continuous support to the system may suspend for some time the process of the treatment and create a communication gap between the patient and the doctor or the other staff members which can have adverse effect on the patient's disease or overall health. Since with the passage of time more IoT technologies and related devices are being incorporated in the medical care systems making them even more complex. So the maintenance of such systems is quite complicated task for which the health centers need to have competent and efficient Information Technology team which can handle these scenarios well.

Summary

The IoT has introduced and pioneered a whole new domain of alternatives and new concepts in the medical care sector. As we have read in the previous sections that just incorporating the IoT technologies and devices with the normal healthcare systems results into getting some important additional information about a patient's condition which makes the doctors able to look even more deep into the disease of a patient. Being able to have treatment while staying at one’s home saves them time and money. It would not be wrong to say that an individual get more control of its life and the way it gets treated for some medical problem when IoT technologies are enabled in ordinary healthcare products.

IoT has necessarily plunged into the medical care sector with a huge number of devices which is in billions and it keeps increasing. However, internet has been used in the medical care sector pretty long time ago, but the integration of IoT in their system has seen boom just lately. According to some stats we are going to see more of technological integration in the medical sector in recent future. As per the report of Mind Commerce medical care IoT will touch by next year 117 USD and the annual growth rate is 15.1 per cent on average [13]. Among other reasons why medical care facilities are working on to minimize the human involvement in some of their tasks is that errors cost a bit too much in health industry and if they have modern technologies enabled devices and accessories to perform these tasks they can easily get rid of the risk that is associated with human factor.

The IoT technologies let a healthcare facility make such extensive and all-round networks that help keep their stuff and personnel – along with the patients - linked up together. This is probably the best internet of things can do to medical care sector as it keeps the diseases to spread, make the overall procedures of the treatment better which eventually results into better results from the viewpoint of both the health center and the patients [72]. However, if there happens to be a smallest of the glitches in the system, it can halt the process, break the cohesion that was there between the patient, medical staff and their equipment. And more importantly keep the doctor from getting the most up-to-date information about their patient which can directly influence the treatment and patient’s health. So the IT support team need to ensure that everything is in order and there is a smooth connection between healthcare equipment and the relevant personnel.

However, at the same time, there exist a threat of IoT enabled healthcare systems being prone to cyber-attacks and in the process the making of other digital medicine gets retarded. [14]

Life logging that we discusses in the previous section can prove to be a way to measure subjective data for the people experiencing psychological problems since this concept changes the way these people are interacting with the healthcare centers. [14]. Moreover, if we have look at some of the healthcare related apps developed by Apple like HealthKit, CareKit and ResearchKit, it gives us an indication that companies like Apple are very much into this. We may well see in the coming years that apps available on such platforms are interacting with the healthcare that we use. Google is not far from this either with GoogleFit. [14]

Now a days more and more healthcare centers are proactively adopting new IoT technologies and they are not limiting the usage of these technologies to only treating the diseases of people but they are also taking into account more aspects of their work like record retention and management of important information about their patients with the usage of cloud services. These modern technologies are benefiting both doctors and patients greatly.

For example the concept of telemedicine is making life of doctors easy by letting them check and treat people even when they are away, and the concept of virtual hospitals is benefiting patients as they do not have to leave their places and can see a doctor while staying home over the internet or using phone applications. Modern day e-commerce sites have been modified in such a way that they now offer a feature that lets people order necessary medicine from home and they get it there.

4.5 Criteria for IoT-enabled system from healthcare perspective

So far we have tried to enlighten the role of Internet of Things in the medical care sector, we are now going to discuss the criteria againstw against which an IoT-enabled system which can result into improved treatment of a disease and better overall outcomes can be chosen.

Criteria

The fundamental criteria against which the best available IoT-enabled systemcan be chosen include overall quality of life, economic prosperity, and contentment.

We now try and describe these criteria one by one and see how sub-criteria are developed from them.

Quality of life

When we are talking of quality of life we include the well-being of a person and also the condition of their disease if they are suffering with any, since our use case considers persons with some kind of neurological problem so we have to include this. Both the overall well-being and the condition of a disease are directly influenced by the age factor. So the IoT-enabled system which is selected should be able to improve disease related condition of the patient and at the same time should improve the overall well-being of them. We know that neurological problems can also prove fatal and especially in aged people so we are going to taking into account the effect of IoT enabled technology/device on fatality as well. Cognitive functioning along with usual life functioning impact greatly the condition of a person with some kind of neurological problem. So do the social relations. So the chosen system should be smart enough to help the patient get better in these aspects. If we keep aside for a moment the disease of the person, the usual well-being and health, the proposed system should be able to help the person in their normal activities, to help them get rid of the sleeping disorders – if any – and also at time when they are unwell, help them manage the medication and get a suitable diet. Lastly, anything that results into fatality should be taken care of. Falling over is pretty common cause of fatalities among people who are aged and suffering from some kind of brain related disease. The proposed IoT integrated system should work on to lower the fatalities caused by this factor.

Economic prosperity

From economic perspective we take into account those possible errors which may occur during the process of the treatment of the disease or the general functioning of the medical care system which will lead to high costs associated with those errors. Apart from high costs those errors will also impact the treatment process negatively and the health of the patient is directly affected this way. Malfunctioning of the medical care devices or the poor management of them can possibly harm the overall environment in which those devices are being used. These environment related issues can be resolved by taking some safety measures for such systems. For example, using fire and safety alarms at the places where these systems are being used.

There can be costs arising from poor medication process affecting the overall treatment. For example, a wrong prescription or distribution of the medicine or not giving it to the patient on time can lead to affecting patient’s health in a negative manner. There will definitely be a cost associated with the corrective measures that would need to be taken then, and part from that, there are chances that a medication error causes such things to the patient that result into fatality, for example, if there are side effects of the wrong medicine including the ones that have the patient feeling dizzy and fallen over.

Just like poor or wrong medication there are chances of poor or wrong identification of the symptoms of a disease. And these can be caused by the personnel of the medical facility or from the device – because of malfunctioning - itself. So, we see all these factors when not taken care of can increase the cost of the overall treatment process. The proposed system should keep an eye on these factors while deciding about the best possible technology for dealing with the neurological problems.

Contentment

Contentment is pertinent to the way the person using the IoT enabled medical care system is looking at it. For example, it takes into account whether the person has faith – factors that bring this in include privacy, reactivity and dependability - in the proposed healthcare system and thinks it will definitely do well to them and are satisfied with the overall functioning of the treatment process. And it is pretty obvious that a person will feel satisfied with the system when it provides control and ease to the user.

4.6 IoT-enabled systems for healthcare

Following are the IoT-enabled technologies/systems which can be used to help treat the neurologically impaired persons.

Cognitive orthotics

These systems can have multiple functionalities and are intended to help individuals who are suffering with cognitive disorders do their routine tasks at a satisfactory level. It is an assistive technology that usually help in a way that it alarms the individual about some specific activity at some specific times which are specified already. This technology is particularly helpful for people with memory loss problem as it can work as a reminder system for them. It integrates technology with neuroscience concepts and help rehabbing such people. These are software based systems which can include artificial intelligence which helps the individual to perform its routine activities independently and that's the major objective of this technology.

Wearable

As much as the technology is advancing, medical care is being more capable of having access to a patient's data that ultimately helps understanding their behavior and making the treatment better. Wearable is one such technology that is normally used for having a record of the person's fitness related data or even location as well. But there are available modern day wearable with ones having technology of big data and artificial intelligence. They are giving some value added benefits to the medical care sector since they are well capable of tracking and monitoring a patient, they can help in diagnosis of the disease, and eventually assisting in the overall treatment of a disease. Since the people with neurological problems particularly need to be monitored consistently, this technology can prove to be really good. Medical care facility personnel and the individuals, they both can benefit from wearable technologies/accessories.

Hearable

Hearable are the equipment which have kind of a microcomputer, put in the ear, and adjusted in the ear canal of an individual. These are something more than a smart earphone which can be used only for listening to the music or call purposes. We can call these devices hybrid since they integrate an earphone functionality with the benefits of wearable technology. Its basic functionalities include helping the individual in hearing with the usage of wireless technology but there is a lot more which this technology offers in healthcare sector especially for the people suffering with neurological problems. For example, it is used in measurements of factors like body temperature, heart rate, blood pressure, and electroencephalogram and pulse oximetry electrocardiogram as well. It can detect a fall which is extremely important from a neurologically impaired person's perspective. Wearable can lead to maintaining some specific health conditions and help with the overall treatment of a disease since they can track the usual activities of the persons carrying them.

If we take a look at Siri from Apple, Alexa from Amazon and also, Vinchi and Vi Sense are good examples that tell wearable are pretty good virtual assistants. [16]

Ambient assisted living

This technology aims at exclusively helping the aged individuals with their quality of life. It gives a paradigm of smart equipment, medical sensors, wireless networks to keep them connected, and some software support to get the system going, it enhances the quality of old people in a way that it helps them do their regular activities on their own and keep doing this for as long as possible. So the basic theme of such a system is to incorporate into the environment of an elderly individual such smart things that would assist them live their life independently. This in turn keep the individual active, happy and connected to the society maintaining a sense of independence at the same time. Safety is another important aspect which is dealt by ambient assisted living.

For example, these technology offers systems for mobile emergency response, video surveillance and for fall detection as well [17]. When the system ensures the safety of the person and it combines with the better quality of life, the person can potentially live independently for more number of years than it would have without such system in the environment of choice of the person [17].

Assistive social robot

These are types of robots which have capabilities to interact socially with individuals, this quality makes them a suitable choice for aged people with respect to their mental health and well-being. These robots play a role of an interface for neurologically impaired people to modern healthcare technologies [18]. Since these robots are designed to be interacting socially with individuals, it gives the patient a sense of companionship which in turn enhances the quality of their life. This type of robots is different than the ones we described in previous types of IoT technologies as those were the devices which can be categorized as assistive robots that only help with the routine activities of the aged people and perform tracking of them but assistive social robots are focusing primarily on giving a companionship like pets do to the individual and it has positive effects on psychological well-being and overall health of the person [71].

Medical care for mentally affected persons has a number of issues since it focuses on filling the gap which is there between those who require medical care and those who are actually getting it. And this type of robots is turning out to be very helpful for this matter as it provides a number of medical care application which are particularly assistive in mental care of elderly people. So incorporating socially assistive robotics into the ordinary medical care systems can result into enhanced safety, improved quality of life and hence more satisfaction and trust of the patient in healthcare system. In this work, we are considering a robot which is able to comprehend the activities of the patient and the environment in which the patient is living. Moreover, it is capable of communicating with the health center when needed.

Embedded devices

Some health related parameters are such that which can be better tracked and monitored when the sensor is very close or even inside the body, for such scenarios, there are available devices which are adjusted inside a body part or just under the derma to give a real time a close view of the happenings inside the body of an individual. Embedded devices are particular good for healthcare applications because of the ease that is associated with the transfer of such devices or sensors with operation which is by no means dependent upon user manipulations. Embedded devices can measure parameters related to different kinds of diseases, store that data and then send it to a remote data center, prompt the individual to perform a necessary action pertinent to a specific health condition, or even do some programmed activity itself [20]. One key feature of this technology is that it makes use of self-monitoring systems for the parameter measurements inside the body of a person, making the person act like a sensor to track – consciously or unconsciously variations in its health condition. Just the same kind of device is considered for this work.

This type of devices include among others, psychological, behavioral and cognitive processes and can potentially get to deep tissue is considerably short response time. [19].

This technology benefits the medical center by giving them opportunity of telemetric measurements of important health related parameters of the patient. At the same time, the individual after getting treated at their own home feel more satisfaction.

One thing that we have seen from all other technologies discussed in this section is that every technology is resulting in shorter and shorter stays in the medical facilities. High cost can be factor. However, there are people with chronic diseases and the ones this work is about, the elderly and neurologically challenged, they require treatment and need to be monitored consistently, so they need to be visiting some assisted living facility more often which they don’t want to or perhaps can’t afford. The use of such technology eliminates the need of frequent visits to the hospital.

5. SOLUTION FRAMEWORK

We now take the actual use case and see how we apply the analytical hierarchy process and get the decision regarding the best IoT technology for the proposed healthcare system. Here are the steps that we will follow:

1. Setting up criteria and sub-criteria
2. Collecting IoT technologies
3. Setting up the hierarchy
4. Evaluating relative priorities
5. Establishing final rankings

5.1 Criteria to decide against

We will be selecting the best IoT technology for the proposed healthcare system based on the following criteria and sub-criteria.

1. **Effectiveness**

We can further divide the criteria and gauge the accuracy of the IoT technology for the proposed healthcare system in terms of the following sub-criteria.

i. Accuracy

Since we are looking for IoT technology that would help monitor an elderly person who may well be suffering with some chronic disease as well, any healthcare system that is used for this purpose including the wearable, those must be tracking and monitoring the individual consistently, meaning that they should remain on all the time to help detect the movements of the person with high accuracy and then after analyzing those movements in a fitting manner communicate that information to many different portable medical care application.

ii. Coverage

Coverage corresponds to the area which is effectively covered by the IoT technology used, Different IoT technologies have different coverage ranges. Which is range is the most suitable depends on the application for which the systems is being designed. From the perspective of a patient, or even a healthy person being tracked and monitored it would vary. There can be application which require the system to be monitoring only within a building or just a room, and there can be application needing a wider coverage area that includes outdoor tracking and monitoring as well. And some of those would prefer a system with scalability. We will try and see how this criteria affects the overall decision of selecting an IoT for a healthcare system.

iii. Latency

The time taken by data to go from a connected device to the control center and reach back to the same device is known as latency. It directly impacts the effectiveness of an IoT-enabled system. IoT is associated with a big amount of data which is gathered and analyzed by the control centers, and the number of devices in IoT is ever increasing; expected to touch 50 billion next year and of this big number, about 31 per cent will be part of the medical sector [27]. Other than that, a large number of IoT devices is relying on cellular networks – which have a large amount of data over them – which slows down the processing rate and we end up with high latency [28]. Communication and processing of such large amounts of data will certainly raise the response time and that in turn will lead to high latency to the individual who is using the IoT-integrated healthcare system. But an elderly person or anyone with some neurological problem would need to be monitored constantly and important health related parameters be recorded in real time. So we would definitely want low latency which usually comes at the cost of power. So we need to select the technology that offer low latency while using as low power as possible.

iv. Data Rate

Data rates are important in healthcare systems. A number of different factors determine how fast health related data can travel through to the control center and reaches back. Distance, for instance, between the healthcare device and the data center, shorter distances allow faster transmission of data. Higher data rates are good for such a system since they help the control center get important information about the person including vital signs and other disease or health related parameters in real time making the process of track and monitor more effective.

Moreover, it makes the system power efficient and the healthcare device can get the job done faster which in turn frees up radio spectrum that can then be used by nearby devices [29]. These are particularly important from the IoT perspective. Higher data rates are usually possible when the range is relatively short. However high capacity networks are possible through high data rates. They are fairly power efficient, so making way for the small batteries to run the device for a longer period of time. Most of the IoT devices run on batteries so it is pretty important aspect that we need to take care of while selecting the IoT technology for a healthcare system.

2. **Acceptability/Applicability**

We can further divide the criteria and gauge the acceptability of the IoT technology for the proposed healthcare system in terms of the following sub-criteria.

i. Battery Life

Battery life is quite important in all the sectors in which IoT technologies are being implemented. In the healthcare sector, the individual related data has to be fed back to the control center and that too in real time, so let's consider for a moment that the battery of the IoT equipment which is monitoring the person goes down, and something serious happen to the person, since the process is halted so the health center would not get any up-to-date information about the person and it can have some serious consequences.

So it the IoT system doesn't have a reliable battery life or it too short , it will imply that IoT technology is doing no good to the person, rather it is proving to be disadvantageous for the individuals using them. So we have to take into this aspect while selecting an IoT technology for a healthcare system.

ii. Privacy and security

IoT devices can produce a significant amount of data. This then has to be transferred, analyzed and probably stored as well. Since we are talking about IoT integrated medical care equipment, data would be personal in most of the cases and quite sensitive too. So the whole process has to be secure. As per Kaspersky, attacks related to smart devices have increased three times in last year [31]. According to [31] cybercrime has targeted the health sector more than any other and the technology usage in domestic abuse is rising, according to [31] smart technologies can sometimes help physical, economic, emotional and psychological abuse. Since the one major use of IoT technology in the healthcare system would be to track and monitor an individual, so if there happen to be any security related vulnerabilities, personal data of the individual is at risk. Also, there are chances that unauthorized access to the system may create for the physical safety of the person carrying that IoT-enabled equipment. So, we need to keep this aspect at forefront while selecting the IoT technology for a healthcare system.

iii. Availability

Availability of an IoT-integrated healthcare system can be seen as the percentage of time for which the system is made available at expected levels of accuracy for its proper functioning. For every Internet of Things technology, there can be many different factors that can limit the availability. Congestion in the normal communication process, for instance. Also, there can be scheduled maintenance that would halt the overall process for some time and limit the availability to some extent. Usually, it is categorized in three different levels with an availability of 99% termed as normal and over 99.9% as high and below 95% is called low availability [32].

Also, no global availability of a particular IoT technology – some technologies are only available in some particular parts of the world - is an issues to be resolved and taken into consideration for the proposed healthcare system. Low Power Wide Area (LPWA) technologies have great capabilities but we must note that none of those is available at global scale. For example, Narrowband IoT (NB-IoT) is for fairly less complex devices which are to be connected to an operator through a licensed spectrum and NB-IoT is being tested in only some parts of Europe and even there it has only a limited availability as just a few operators are piloting and testing it [33]. And if we consider the use of LoRa, then to connect to these networks if we are outside some specific markets in Europe, we would require to deploy our own network gateway [33]. But it pretty encouraging to note that according to some sources low power wide area technologies will be providing coverage for the entire population of the world by 2022 [34].

3. Cost

We can further divide the criteria and evaluate the cost for incorporating the IoT technology in the proposed healthcare system with the following sub-criteria.

i. Power Consumption

This aspect is linked also with the battery life. According to [30], 3 major factor that affect the 'long term sustainability of the IoT' include energy as one of those, also wireless technologies are way more power consuming than wired ones.

However, modern technologies are getting more efficient energy-wise. So we will take this aspect into consideration while selecting the IoT technology for the healthcare system that it should consume the least possible amount of power and may use alternative – other than the battery – power sources if available. IoT technologies which are energy efficient and take low power will ultimately result into longer battery lives and continuous operation of the healthcare device.

ii. Cost of related equipment and infrastructure

Cost is one of the main factors to look for while selecting an IoT technology for a healthcare or even any other smart system and it keeps varying depending upon the type of system being developed. And there are a number of dimensions through which we can look into the cost of implementing an IoT enabled solution. For example, money, time to implement and deploy the system, space, and even energy that it consumes. Money is what we need to buy the system components, sensors for examples, and the cost associated with having the system run smoothly. There are some technologies that make use of existing systems resources – network, for example – these are fairly economical to use. So, we'll have a look at this aspect while deciding on the best IoT technology among available ones for healthcare system.

iii. Complexity

IoT technologies offer a variety of advantages but at the same time its implementation can be challenging. IoT-integrated systems are usually made up of many different technologies which have their own kind of development and it constitutes a quite complex environment. IoT technology that we will employ in the healthcare system will need to support the process throughout; from the detection of movements, communicating the person related information with the control center, comprehending it and the final action as well. Handling a significant amount of data can have some issues, for instance, the keeping the information and the environment in which it is being transferred secure. Also, there is not an IoT solution that works for anything and everything. So we must select a technology that offers scalability and should encourage robust data management throughout the process.

5.2 IoT Technologies to choose form

Here is the list of the Internet of Things technologies that can potentially be used in the proposed healthcare system. Our task is to analyze all of these with respect to the criteria and sub-criteria described above and select the most suitable technology.

i. RFID

RFID stands for Radio Frequency Identification Technology. As the name suggests, this technology is used to identify objects, it does so through RFID tags and labels which are directly affixed or connected with the objects. Kind of a two way communication happens in the process where a reader transmits a signal to the tag and receives the response sent by the tag that carries some information about it. And then the reader feeds the response to a RFID software running on a connected computer for analysis [35]. From the safety point of view of the elderly, this technology can prove to be beneficial. There has been significant rise in the mistreatments in medical care sector, reason being improper identification of the individual being treated or the medicine administrated to them [36]. RFID technology integration into the ordinary healthcare systems can potentially prevent the health related errors caused by misidentifications.

ii. EnOcean

This technology is particularly good for energy harvesting wirelessly at extremely ultra-low power, mainly used in building automation, it is now being used in other sectors including the healthcare [38]. These devices are battery less and quite easy to install since there is no use of wires. These devices make use of solar panels and are able to function properly for quite a few days even when there is no light [37]. EnOcean integrated systems use micro energy convertors in conjunction with ultra-low power electronics.

Range for which these devices are effective depends if being used indoor or outdoor.

iii. NFC

Near Field Communication is a short range solution for peer to peer communication wirelessly. This technology is fairly simple and cheap to implement, intuitive to use and is particularly good for keeping the medical records secure. According to a report by Transparency Market Research medical sector is among the fastest growing sections of this technology [39]. There are number of ways it can help the healthcare system. It gives security against the unauthorized logical access to health related of the user. It can ensure real time updates about the health condition of an individual [39].

NFC technology is particularly applied for portable devices, smart phones, for example. It makes the health related data of the person easy to carry, access and manage. In a healthcare system integrated with NFC technology a person can simply use a smartphone for identification purpose and then health related data can be accessed and associated with that person and this system also allows the remote monitoring of the person and drug administration [40].

iv. Bluetooth-low energy (BLE)

Low energy Bluetooth is an IoT technology that lets Bluetooth integrated devices to ‘talk’ with each other in a short range. It is different from conventional Bluetooth in a way that it uses way less power and then accordingly range is also less than that - around half of the usual Bluetooth connection - but it does provide most of the connectivity [41]. The connection that BLE provides is robust and reliable [p].This technology is also termed as Bluetooth Smart. Since the healthcare devices tend to be running at low power, so BLE can prove to be a good choice because it can make devices run for years without a recharge or replacement of power source [o]. When this technology is coupled with RTLS, it allows event-driven triggers which on the basis of proximity sensor data and timing can assist streamline many of the treatment procedures [42].

v. Weightless SIG

We need to look at solutions which can work over long distances. For example, when the person being tracked and monitored is outdoor. But gain, we would definitely want the system to be working at low power, so the solution is a technology that gives long ranges and takes low power. Weightless is one those technologies that provides wireless connectivity for low-power wide-area networks which re used particularly in the IoT sector [44]. Weightless technology works fairly similar to SigFox. It has three different version with everyone having its own requirements. One of the plus points that Weightless technologies gives over others is that it is the only open standard technology which works on unlicensed spectrum [44]. Moreover, it is pretty power efficient and allows two way communication [44]. Another top functionality that it offers is it allows to synchronize a network, meaning that it enables to schedule uplink transmissions which in turn enhances the scalability. Also, from the security perspective, it encrypts the communication link between a device and the relevant base station [45].

vi. Sigfox

Another wireless connectivity solution for long range is Sigfox. The range that it provides is better than WiFi and less than a cellular network. This technology makes use of ISM - Industrial, Scientific and Medical - radio bands that do not need licenses and are free to use. It makes communication possible between objects over a quite narrow spectrum by making use of Ultra Narrow Band technology [46]. This technology is particularly good for application which have smaller batteries and consume low amounts of power - WiFi can be an option in such scenarios but the range it provides a bit too short - and used for relatively lower levels of data transmission – for example, Sigfox allows data transfer rates of 10-1000 bits/sec consuming just 50 mW [of power, and it gives a standby time of almost 2 decades with only a 2.5 Ah battery [46]. Sigfox provides a network which is quite power efficient, robust and gives it scalability as well by supporting a huge number of devices which are operating on battery, he number can go in million as it covers an area of several kilo meters. Healthcare systems can benefit from this. The range that Sigfox provides depends on the environment it is being used in; urban or rural.

vii. LTE

An IoT device/application which need to function over relatively large area can utilize capabilities of cellular networks like GSM, 3G, and LTE etc. [46]. Since cellular technology can obviously enable large amounts of data transfers so accordingly the power it is going to take – in case of 4G in particular - would be high for a big number of applications and it can prove to be quite expensive. But at the same time, it can prove to be an ideal solution for scenarios where communication has to happen for lower amounts of data at low bandwidth, for example when this technology is being used by sensors used for measurements of vital signs and other health related parameters [46]. And with the 5G in the purview, the future of cellular technology for IoT devices seem promising.

Moreover, LTE technology enabled systems would not need to have separate private networks for themselves, they can rather utilize the very network that ordinary smartphones use [47]. So this way, LTE technology gives IoT enabled healthcare equipment an alternative of LPWAN – low-power wide-area network – we also have other technologies for such networks but those area not cellular based and function in unlicensed bands, for instance, Sigfox and LoRa [47].

viii. Zigbee

Zigbee is an open standard technology used for low power, cheap to implement, needing low bandwidth wireless connectivity in IoT devices. However, it doesn't offer super high data rates. It works particularly well when the transmissions have to happen within a home or building and are not so frequent [46]. Among many other Zigbee enables fairly simpler and cheaper to implement wireless personal area networks [48]. Since it does not take a great amount of power, this limits the range of this technology to just about 100m, and the range would depend on the environmental factors as well. However, we can have these devices for longer distance transmissions making use of mesh network of intermediate devices [48]. Their ability to provide latency and the data rates that these devices offer – 250 kbps - well suit those health related scenarios where data is transmitted in a sporadic manner [48]. One of Zigbee's profiles is Zigbee RF4CE that works particularly well in complex systems by making them highly secure, power efficient, scalable – with a considerably high node count - and robust [46].

ix. LoRa

LoRa or LoRaWAN is in terms of a number of aspects like Sigfox, for example, it is applicable to applications requiring wide area network. LoRa technology support power efficient wide area networks which are used for cost efficient, low bandwidth, and two way wireless communication in IoT. This technology does not use a large amount of power but supports big enough networks – where number of devices may reach several millions – at data rates of 0.3-50 kbps [46]. Some key features of LoRa that make it suitable for medical care applications include low power, reliable performances over long range, and being cheap. LoRa integrated healthcare systems help enable continuous tracking and monitoring of the individuals in a safe manner [49]

Out of other benefits that LoRa provides one is the possibility that it lets the deployment of private gateways which are not costly in the formation of one's own network. It will cover an area of around 3km a gateway. And this can help using a single gateway for indoor communication that can suit a number of IoT solutions [50]. Again, the range depends on the environment in which the technology is being used.

x. NB-IoT

NB-IoT stands for Narrowband Internet of Things. It is a LPWA technology - low power wide area – which is standards-based unlike the ones we discussed above. Key features that this technology offers are low power consumption, efficient spectrum utilization – particularly in deep coverage - and an improved capacity of the system. It supports a large number of use cases where battery life can be more than a decade [51].

This technology can exist in parallel with other mobile networks like 3G and 4G because it is supported by majority of the mobile equipment and module manufacturers [51]. Also, it can utilize security-related characteristics of those networks.

We know that measuring different disease or overall health related parameters consistently is one prime feature that we would want to have in the healthcare system we are looking to have. For such high-degree and short-lived requirements of the system, NB-IoT can potentially be the solution since it offers communications over wide area, long range at low data rate for equipment having great battery time and low processing complexity [52].

xi. WiFi

Typically this technology is used for wireless local area network of different IoT or other devices. Its availability and extensive usage in home environments make it an obvious solution for many for connectivity within a limited area like a home or building [ii]. Some key aspects that make it suitable for incorporating into the medical care systems are existing infrastructure which is available widely and easily, enabling fairly fast transmission of data within its premises, and its ability to transfer considerably large amounts of data [46].

This technology is based around 802.11 family of standards from IEEE and at the moment, standard of this technology which is used most frequently in homes or other similar environments is 802.11ac [54]. It gives a throughput which is over one Gbps – it would depend on the channel frequency and also the no. of antennae used - and it sounds pretty well for high amounts of data transfers but can prove to be expensive in terms of power consumption for IoT devices [46]

Range that WiFi technology offers varies depending on the standard being considered, other factors that affect the maximum range of WiFi include the environment and any kind of interference being caused by radio frequency signals from other sources [55]. WiFi Standard that we are talking about gives a maximum range of 230 feet and a throughput which has a theoretical maximum of 1.3 Gbps [55].

The completed model of the analytic hierarchy process for the actual problem is given next. All the IoT technologies are mutually compared with each other with respect to all the sub-criteria but for clarity only one of those is shown in the figure.

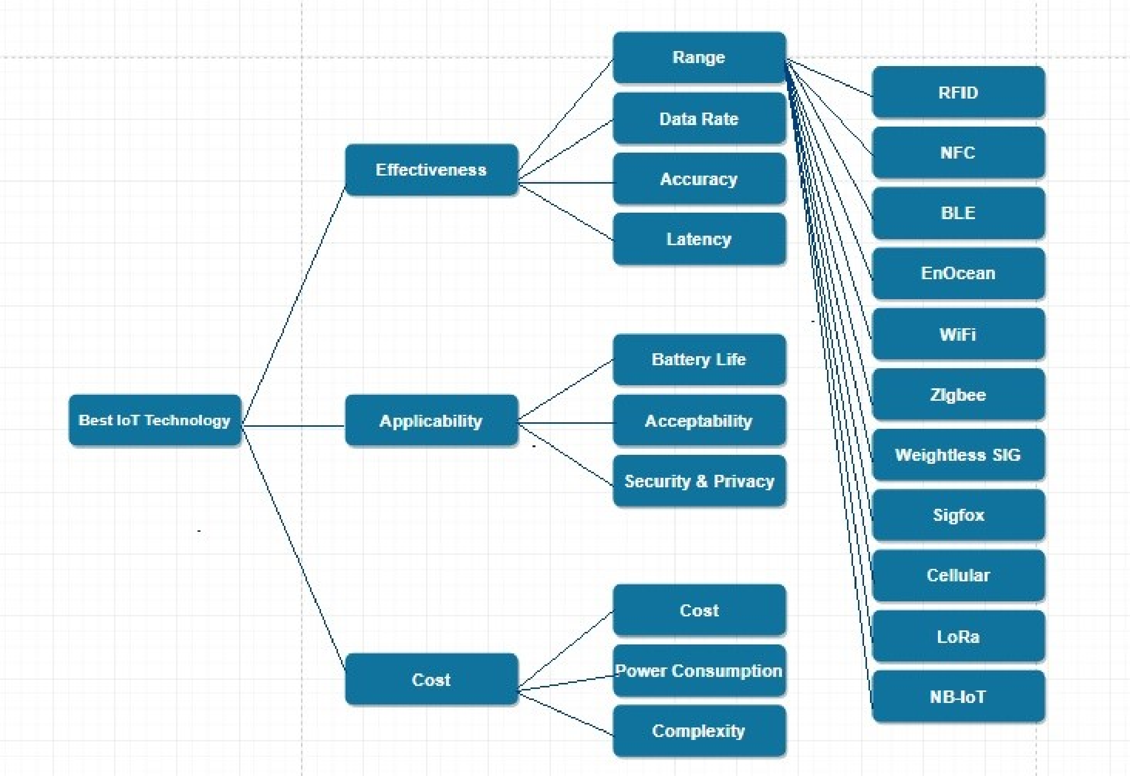

Figure 5 Completed AHP model for the use case

5.3 Setting up Hierarchy

We use analytical hierarchy process to find out the relative importance of the IoT technologies and the criteria on the basis of given weightages. Now that we have defined the criteria and sub criteria against which we will be deciding for the best IoT technology for the proposed healthcare system, we can now establish a hierarchy of the model solution. The figure 7 represents the whole AHP model. It shows the relative weights as well but the calculations are illustrated in the next section.

5.4 Evaluating Relative Priorities

As explained in the earlier sections that this process – Analytical Hierarchy Process – was presented by Thomas Saaty, it proves to be an effective decision making model that helps the decision makers to evaluate their respective priorities and based on those get to a decision. We try and explain a couple of simple consecutive steps which are followed to implement this hierarchical model.

First step is already done which was to establish a hierarchy for the model solution having all the criteria, sub-criteria and alternatives – IoT technologies in this case – available.

In the second step, starting with the main criteria, all of those are compared against each other – also called pairwise comparisons – by utilizing the weights assigned to each of them based on the relative importance. Weight values are taken from Saaty's ratio scale of 1-9. All the possible values along with their description are given in the table below.

Table 2 Satty's Ratio Scale of relative importance

Value	Description
1	Equally important
3	Slightly more important
5	More important
7	Strongly more important
9	Extremely more important
2, 4, 6, 8	Intermediate

All of this is done after making a square matrix in which first row and column are the same entries – all the criteria, sub-criteria or the alternatives available depending upon what quantities are being compared pairwise – then each element of the first column is compared pairwise with the all the elements of the first row one by one and the data gathered is organized in the matrix. Diagonal elements being same element getting compared to itself always give one.

In the next step, consistency of the matrix is checked. Consistency Ratio (CR) is the ratio of Consistency Index (CI) and Random Index (RI). The table for Random Index is available in [103] - which is average CI of randomly filled matrices - for a certain value of 'n' – the order of the pairwise comparison matrix – and the Consistency Index is about Eigen values.

$$CR = \frac{CI}{RI}$$

$$CI = \frac{\lambda_{max} - n}{n-1}$$

Here λ_{max} represents the maximum Eigen value and 'n' is the order of the pair-wise comparison matrix. For having an acceptable level of consistency in our solution, we need to have CR value less than 0.1

Then we move on to getting the relative rankings of the criteria/alternatives. After checking the consistency ratio, we normalize the matrix, we do so by dividing each of the element by its column sum. And then take the average of each row that gives the priority vector, and this is what we use to get rankings. This method of getting relative priorities is also called Approximation method. We will be using Matlab to solve these matrices and checking the consistency of the weight values.

And finally we get the rankings of IoT technologies based on the weight values with respect to all the sub-criteria. We do so by constructing a matrix that consist of all the 10 priority vectors from all sub-criteria matrices. And then the matrix is multiplied with the priority matrix of the main criteria. This multiplication will result into a column matrix with every element giving the relative priority value of each of the IoT technology considered in this problem. From there we can see which IoT technology best suits the proposed paradigm.

The following table available in [103] gives the Random Index values that we would be using later on.

Table 3 Random Index Values

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

5.5 Evaluation Process

Now we evaluate the relative priorities of all the criteria, sub-criteria and IoT technologies. Extensive study has been done over the internet to get the weight values for most of the IoT technologies with respect to each and every sub-criteria from the perspective of a medical care system deigned particularly for the elderly people or ones having some neurological problems, dementia for example. But it is to be noted that we have also considered regular people and their activities for selecting suitable technology and giving weight value accordingly for the proposed paradigm. We have also taken into consideration the overall well-being of normal people. There were found numerous reliable sources including IEEE articles which give numerical values for most of the criteria considered in this problem, and some were analytically analyzed for getting the relative weight values based on conclusions of those sources. An appendix is given at the end of this document that contains the data collected for comparison purpose.

The main criteria matrix is pretty much subjective and we have given quality of the service of an IoT technology – its effectiveness – more value than the overall cost of the system and cost is more important than the applicability of the IoT technology.We went on further to check the reliability of our judgments by computing the consistency ratio of each matrix involved in the process. We will give the value of consistency ratio (CR) after each matrix and ensure it falls within the acceptable region.

Now we make pairwise comparisons and start with the main criteria.

Since the effectiveness of the systems is directly related to the quality of life of the individual which include the overall well-being and the disease related condition of the person suffering with dementia. Taking care of these things is the ultimatele goal of the proposed system, the system can meet the expectations if is capable of helping the people with their cognitive functioning, social relations, and above all able to respond to any emergency. For this, the system needs to have good accuracy, as low as possible latency, and data rates are particularly important in some cases where a system needs to connect to the control center immediately to get important information about the person including vital signs and other disease or health related parameters in real time making the process of track and monitor more effective So the effectiveness of the system is taken as the most important criteria, followed by the cost which needs to be at a level which is affordable to a common person, the sub-criteria that we have chosen directly influence the cost of the device. So, cost of the device is taken as more important criteria than the acceptability of the IoT technology to be used for the proposed system.

Table 4 Pairwise comparison matrix for main criteria

Goal: **Most important criteria**	Effectiveness	Acceptability	Cost
Effectiveness	1	5	3
Acceptability	1/5	1	1/3
Cost	1/3	3	1

Fractional values are now converted to decimal and column sum is taken.

We will now find the normalized matrix, and take average of each row to get the priority index.

We have used Matlab to solve the pairwise comparison matrices. Here is how we can normalize a matrix in Matlab.

```
[row, col] = size(X);
 for i=1:col
  Normalized(:,i)= X(:,i)/sum(X(:,i));
 end
```

Here 'X' is the size of the matrix which we want to normalize.

Table 5 Normalized Criteria Matrix

Criteria	Effectiveness	Acceptability	Cost	Priority Vector	Ranking
Effectiveness	0.6523	0.5555	0.6977	0.6333	1
Acceptability	0.3752	0.1111	0.0769	0.1062	3
Cost	0.2172	0.3333	0.2308	0.2605	2
	1.000	1.000	1.000	1.000	

The consistency ratio for the criteria matrix is found to be 0.0559.

Now we evaluate matrices of sub-criteria.

Considering the effectiveness of the proposed healthcare system, accuracy is the most important factor for its proper functioning and meeting the desired results, if anything goes wrong with it, the system may result in poor disgnosis and then ultimately poor decisions from the medical staff side. Latnecy is the second most important factor for the proposed system since we are dealing with the people who are neurologically challenged who need to be monitored in real time. Latnecy is followed by data rate which is particularly important in emergency scenairios.

For applicability, battery life ts taken as the most important sub-criteria. We expect from an IoT-enabled device that it last for a long time and we do not have to spend again and again on changing the batteries or their maintanence. Privacy and security are some important factors to take into account while selecting the most appropriate IoT technology for the proposed system since the major functions of the healthcare system would be to track and monitor an individual, so if there happen to be any security related vulnerabilities, personal data of the individual is at risk. But availability is something we need to give a little more importance as some of the technologies that we have chosen are not available worldwide, so for a particular region, it first needs to be ensured that the IoT technology is available and can be incorporated to the proposed healthcare system.

For the sub-criteria of cost, the weight values are fairly straightforward, the cost associated with the infrastructure and equipment used for the proposed system is more important than the cost related to the power consumption.

Table 6 Pairwise Comparison Matrix for Sub-Criteria

Goal: Effectiveness	Range	Latency	Data Rate	Accuracy
Range	1	1/5	1/3	1/7
Latency	5	1	3	1/3
Data Date	3	1/3	1	1/5
Accuracy	7	3	5	1
Goal: Acceptability	Battery life	Privacy	Availability	
Battery life	1	5	3	
Privacy	1/5	1	1/3	
Availability	1/3	3	1	
Goal: Cost	Power consumption	Cost	Complexity	
Power consumption	1	1/3	3	
Cost of equipment	3	1	5	
Complexity	1/3	1/5	1	

After checking their consistency ratio, we solved them using the method given in previous section – we have used Matlab for these calculations - and the results are shown in the next table for all the criteria and respective sub-criteria.

```
priority_vector= mean(Normalized,2)
```

It just takes the mean of each row of the normalized matrix and results into the priority vector.

Table 7 Priority Vector and rankings of Sub-Criteria

Criteria	**Priority Value**	**Rank**	**Sub-criteria**	**Priority Value**	**Rank**
Effectiveness	0.633	1	Range	0.036	7
			Latency	0.166	3
			Data rate	0.077	4
			Accuracy	0.353	1
Acceptability	0.106	2	Battery Life	0.067	6

			Sec&Privacy	0.011	10
			Availability	0.027	9
Cost	0.261	3	Power Consumption	0.068	5
			Cost	0.167	2
			Complexity	0.028	8

Consistency ratio is calculated to be 0.0211 for effectiveness sub-criteria, 0.0559 for both acceptability and cost sub-criteria. Priority values of these sub-criteria are multiplied with respective value from the criteria matrix, for example, priority values of range, data rate, accuracy and latency are multiplied with priority value of effectiveness taken from priority vector of criteria matrix. This way we can rank all the sub-criteria with respect to their relative importance in deciding the IoT technology.

Now we make pairwise comparisons of all the IoT technologies considered against each of the sub-criteria one by one.

Effectiveness

i. Range

Weight values for the pairwise comparison matrices of IoT technologies are based on the Table 20 given in the appendix. We see from the 'Range' column of the table that RFID has the lowest range among the chosen technologies. It is to be mentioned here that we have considered only the passive type of RFID tags. Range in that case is not even 1m while in the case of NFC, range is almost double and it goes on increasing for other technologies with SigFox having a range as much as 40km in rural areas. We have got to use a scale of 1-9 to map this big difference of ranges in Table 8.

Table 8 Pairwise Comparison Matrix for IoT technologies with respect to 'Range'

Range	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1/2	1/3	1/4	1/5	1/6	1/7	1/9	1/8	1/7	1/8	0.0134
NFC	2	1	1/2	1/3	1/4	1/5	1/6	1/9	1/8	1/7	1/7	0.0170
BLE	3	2	1	1/2	1/3	1/4	1/5	1/9	1/7	1/6	1/7	0.0227
EnOcean	4	3	2	1	2	1/2	1/3	1/7	1/5	1/5	1/5	0.0385
WiFi	5	4	3	1/2	1	1/2	1/3	1/7	1/6	1/5	1/5	0.0390
Zigbee	6	5	4	2	2	1	1/3	1/7	1/6	1/5	1/6	0.0528

W-Sig	7	6	5	3	3	3	1	1/5	1/4	1/3	1/4	0.0784
Sigfox	9	9	9	7	7	7	5	1	3	3	3	0.2680
LTE	8	8	7	5	6	6	4	1/3	1	3	1/3	0.1608
LoRa	7	7	6	5	5	5	3	1/3	1/3	1	1/3	0.1216
NB-IoT	8	7	7	5	5	6	4	1/3	3	3	1	0.1878

Consistency ratio in calculated to be 0.0765. As expected, wide area IoT technologies are having way more priority values with respect to range.

ii. Data rate

If we have a look at the 'Data rate' column of Table 20, we see that RFID has a better value than Zigbee with a very little difference, this minute difference is reflected in Table 9 following the scale given in Table 2. Weight value of 3 for RFID against Zigbee simply says that RFID is just a little more important than Zigbee with respect to data rate. Similarly, as for other technologies which have higher data rates, we have given more weight values, as we can see from the same colomn that LTE and WiFI has data rates in Mbps and Gbps respectively, so those have the highest weight values in Table 9.

Table 9 Pairwise Comparison Matrix for IoT technologies with respect to 'Data Rate'

Data Rate	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	½	1/3	3	1/9	3	1/7	3	1/7	3	1/5	0.0369
NFC	2	1	1/3	3	1/9	3	1/7	3	1/7	5	1/3	0.0448
BLE	3	3	1	5	1/7	5	1/5	5	1/3	7	1	0.0792
EnOcean	1/3	1/3	1/5	1	1/9	1/3	1/7	3	1/7	3	1/5	0.0239
WiFi	9	9	7	9	1	9	5	9	5	9	7	0.3377
Zigbee	1/3	1/3	1/5	3	1/9	1	1/7	3	1/7	3	1/5	0.0296
W-Sig	7	7	5	7	1/5	7	1	7	1	9	3	0.1652
Sigfox	1/3	1/3	1/5	1/3	1/9	1/3	1/7	1	1/9	1/3	1/9	0.0141
LTE	7	7	3	7	1/5	7	1	9	1	9	3	0.1586
LoRa	1/3	1/5	1/7	1/3	1/9	1/3	1/9	3	1/9	1	1/7	0.0176

NB-IoT	5	3	1	5	1/7	5	1/3	9	1/3	7	1	0.0924

Consistency ratio of this matrix is found to be 0.0923.

iii. Accuracy

'Accuracy' colomn of Table 20 shows that RFID has accuracy is way more than that of NFC, but we have other technologies as WiFi, LTE and SigFox which have even higher accuracy. On the other hand, technologies as EnOcean and LoRa have poor accuracies, the same colomn shows that NB-IoT have higher accuracy than LoRa but it is not as good as, for example, WiFi. We have mapped these levels of accuracy in Table 10 following the scale given in Table 2.

Table 10 Pairwise Comparison Matrix for IoT technologies with respect to 'Accuracy'

Accuracy	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	3	1/3	5	1/5	3	3	1/7	1/5	1/3	1/5	0.0517
NFC	1/3	1	1/5	1	1/7	1/3	1/3	1/5	1/5	1/5	1/7	0.0189
BLE	3	5	1	5	1/3	3	5	1/3	1/3	1	1/3	0.0825
EnOcean	1/5	1	1/5	1	1/7	1/3	1	1/5	1/5	1/5	1/7	0.0201
WiFi	5	7	3	7	1	5	7	3	3	3	3	0.2371
Zigbee	1/3	3	1/3	3	1/5	1	3	1/3	1/3	1/3	1/5	0.0420
W-Sig	1/3	3	1/5	1	1/7	1/3	1	1/5	1/5	1/3	1/5	0.0262
Sigfox	7	5	3	5	1/3	3	5	1	1/3	1	1/3	0.1088
LTE	5	5	3	5	1/3	3	5	3	1	3	1	0.1483
LoRa	3	5	3	5	1/3	3	3	1	1/3	1	1/3	0.0920
NB-IoT	5	7	5	7	1/3	5	5	3	1	3	1	0.1726

Consistency here is found to be 0.0843.

iv. Latency

If we look at the 'Latency' colomn of Tabel 20, we find out that low range IoT technologies perform exceptionally with respect to latency. For example, NFC, BLE and Zigbee have latency in milli seconds whereas NB-IoT has latency in seconds, SigFox can have latency up to 10s. Even for technologies with latency in ms, there is still difference in latencies with BLE having the lowest latency of 2.5 ms, this has been reflected in Table 11.

Table 11 Pairwise Comparison Matrix for IoT technologies with respect to 'Latency'

Latency	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1/3	1/5	3	1/3	1/5	5	5	1/5	5	5	0.0688
NFC	3	1	1/5	3	1/3	1/4	3	6	1/4	5	5	0.0781
BLE	5	5	1	5	3	3	7	9	2	7	7	0.2427
EnOcean	1/3	1/3	1/5	1	1/6	1/5	3	5	1/6	3	3	0.0454
WiFi	3	3	1/3	6	1	1/3	5	7	1/3	5	5	0.1147
Zigbee	5	4	1/3	5	3	1	6	8	2	7	7	0.1855
W-Sig	1/5	1/3	1/7	1/3	1/5	1/6	1	3	1/6	3	3	0.0330
Sigfox	1/5	1/6	1/9	1/5	1/7	1/8	1/3	1	1/8	1/3	1/3	0.0137
LTE	5	4	1/2	6	3	1/2	6	8	1	7	7	0.1716
LoRa	1/5	1/5	1/7	1/3	1/5	1/7	1/3	3	1/7	1	1/3	0.0206
NB-IoT	1/5	1/5	1/7	1/3	1/5	1/7	1/3	3	1/7	3	1	0.0259

Consistency ratio in latency criteria is 0.0883.

Acceptability

i. ***Battery Life***

If we see the 'Battery life' colomn of Table 20, clearly the IoT technologies have generaly very good battery life with an exception for a couple of those. EnOcean and NFC do not even need a battery to operate. This technology is particularly good for energy harvesting wirelessly at extremely ultra-low power. Same is the case with NFC, it does not require a battery. Technologies as LoRa, NB-IoT and SigFox, they all have battery life in excess of 10 years. RFID has a battery life of 20 years. WiFi performs poorly in this aspect with a battery life of just a couple of days, so is the case with BLE. We have mapped this difference in battery life of the chosen ioT technologies in Table 12.

Table 12 Pairwise Comparison Matrix for IoT technologies with respect to 'Battery life'

Battery life	RFID	NFC	BLE	EnOcean	WiFi	Sigfox	W-Sig	Z-bee	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1/7	1	1/7	5	1/3	1/3	3	1/5	1/7	1/7	0.0296
NFC	7	1	7	1	9	5	5	7	5	1	1	0.1874
BLE	1	1/7	1	1/7	5	1/3	1/3	3	1/5	1/7	1/7	0.0296
EnOcean	7	1	7	1	9	5	5	7	5	1	1	0.1874
WiFi	1/5	1/9	1/5	1/9	1	1/7	1/7	1/5	1/7	1/9	1/9	0.0117
Sigfox	3	1/5	3	1/5	7	1	1	5	1/3	1/3	1/3	0.0588
W-Sig	3	1/5	3	1/5	7	1	1	5	1/3	1/3	1/3	0.0588
Zigbee	1/3	1/7	1/3	1/7	5	1/5	1/5	1	1/5	1/5	1/5	0.0234
LTE	5	1/5	5	1/5	7	3	3	5	1	1/3	1/3	0.0874
LoRa	7	1	7	1	9	3	3	5	3	1	3	0.1810
NB-IoT	7	1	7	1	9	3	3	5	3	1/3	1	0.1448

Consistency ratio for this matrix is 0.0730.

ii. Security

'Security' colomn in Table 20 shows that all the chosen IoT technologies offer some kind of security. RFID, Zigbee, NB-IoT and Weightless SIG having pretty strong security whereas LoRa and EnOcean are on the lower side. So, security offered by NB-IoT is assumed to be having a weight value of 7 as compared to LoRa. Similarly, NFC offers a good level of security but not as good as RFID, so have given RFID more importance in this aspect and a weight value of 3 is given in the pairwise comparison with NFC.

Table 13 Pairwise Comparison Matrix for IoT technologies with respect to 'Security & Privacy'

Security	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	3	5	7	7	1	1	5	1	7	1	0.1571
NFC	1/3	1	5	7	7	1/3	1/3	5	1	7	1	0.1134
BLE	1/5	1/5	1	3	3	1/5	1/5	1	1/5	3	1/5	0.0371
EnOcean	1/7	1/7	1/3	1	1	1/7	1/7	1/3	1/7	1	1/7	0.0183

WiFi	1/7	1/7	1/3	1	1	1/7	1/7	1/3	1/7	1	1/7	0.0183
Zigbee	1	3	5	7	7	1	1	5	1	7	1	0.1571
W-Sig	1	3	5	7	7	1	1	5	1	7	1	0.1571
Sigfox	1/5	1/5	1	3	3	1/5	1/5	1	1/5	3	1/5	0.0371
LTE	1	1	5	7	7	1	1	5	1	7	1	0.1430
LoRa	1/7	1/7	1/3	1	1	1/7	1/7	1/3	1/7	1	1/7	0.0183
NB-IoT	1	1	5	7	7	1	1	5	1	7	1	0.1430

Consistency ratio for the security sub-criteria matrix is calculated to be 0.0262.

iii. Availability

If we take the 'Availability' column of Table 20, we see that technologies as RFID, NFC and WiFi are readily available, whereas EnOcean, Weightless SIG are not so common. Wide area technologies as LoRa and NB-IoT are not available in some parts of the world. So, technologies which are easily available everywhere are given higher weight values in Table 14, for example. WiFi is given a weight value of 5 in pairwise comparison with Weightless SIG.

Table 14 Pairwise Comparison Matrix for IoT technologies with respect to 'Availability'

Availability	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1	1	5	3	7	7	3	5	5	5	0.1946
NFC	1	1	1	5	3	7	7	3	5	5	5	0.1946
BLE	1	1	1	5	3	7	7	3	5	5	5	0.1946
EnOcean	1/5	1/5	1/5	1	1/3	3	3	1/3	3	3	3	0.0604
WiFi	1/3	1/3	1/3	3	1	5	5	1	3	3	3	0.0932
Zigbee	1/7	1/7	1/7	1/3	1/5	1	3	1/5	1/3	1/3	1/3	0.0233
W-Sig	1/7	1/7	1/7	1/3	1/5	1/3	1	1/5	1/3	1/3	1/3	0.0181
Sigfox	1/3	1/3	1/3	3	1	5	5	1	3	3	3	0.0932
LTE	1/5	1/5	1/5	1/3	1/3	3	3	1/3	1	3	3	0.0509
LoRa	1/5	1/5	1/5	1/3	1/3	3	3	1/3	1/3	1	3	0.0424
NB-IoT	1/5	1/5	1/5	1/3	1/3	3	3	1/3	1/3	1/3	1	0.0345

Consistency ratio in this case is 0.0582.

Cost

i. Cost of the infrastructure and related equipment

If we take the 'Cost' column from Table 20, we see that RFID, NFC and Zigbee are ultra low cost technologies; way lower than a dollar. SigFox and LoRa are not expensive either, but comparatively these technologies are a bit higher in cost; up to 5 dollars. However, technologies as EnOcean and NB-IoT are fairly more expensive in comparison to RFID and Zigbee so we give a weight value of 7 in pairwise comparison against EnOcean and NB-IoT as NB-IoT alone cost more than 20 dollars. Similarly, all other technologies are mapped in Table 15 as per values taken from the same column of Table 20.

Table 15 Pairwise Comparison Matrix for IoT technologies with respect to 'Cost'

Cost	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1	3	7	3	1	3	2	7	4	6	0.1736
NFC	1	1	3	7	3	1	3	2	7	4	6	0.1736
BLE	1/3	1/3	1	5	2	1/3	1	1/3	5	1/3	4	0.0679
EnOcean	1/7	1/7	1/5	1	1/5	1/7	1/5	1/7	1/3	1/5	1/3	0.0156
WiFi	1/3	1/3	1/2	5	1	1/3	3	1/3	5	1/3	3	0.0684
Zigbee	1	1	3	7	3	1	3	1/2	7	4	6	0.1551
W-Sig	1/3	1/3	1	5	1/3	1/3	1	1/3	5	3	5	0.0742
Sigfox	1/2	1/2	3	7	3	2	3	1	7	3	4	0.1482
LTE	1/7	1/7	1/5	3	1/5	1/7	1/5	1/7	1	1/4	1/3	0.0203
LoRa	1/4	1/4	3	5	3	1/4	1/3	1/3	4	1	3	0.0741
NB-IoT	1/6	1/6	1/4	3	1/3	1/6	1/5	1/4	3	1/3	1	0.0291

Consistency ratio of cost sub-criteria matrix is 0.0752.

ii. Power consumption

For weight values of pairwise comparison matrix of power consumption, we consider 'power consumption' column of Table 20. Clearly, LTE is the most power consuming technologies among the chosen ones. WiFi does not seem a good choice for the proposed healthcare system too. So these technologies are given lowest weight values in pairwise comparisons with other technologies. For example, EnOcean is an energy harvesting technology that works at ultra low power, so it is given a weight value of 9 when compared with LTE and 5 in case of WiFi. RFID, NFC and BLE consume very low amount of power, so for those, EnOcean is given a weight value of 3. Table 16 reflects the power consumption of the IoT technologies based on the scale given in Table 2.

Table 16 Pairwise Comparison Matrix for IoT technologies with respect to 'Power Consumption'

Power consumption	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1	1/3	1/3	3	1/3	1/3	1/3	7	1/3	3	0.0537
NFC	1	1	1/3	1/3	3	1/3	1/3	1/3	7	1/3	3	0.0537
BLE	3	3	1	1/3	5	3	3	3	9	1/3	5	0.1408
EnOcean	3	3	3	1	5	3	3	3	9	1/3	5	0.1700
WiFi	1/3	1/3	1/5	1/5	1	1/5	1/5	1/5	5	1/5	3	0.0317
Zigbee	3	3	1/3	1/3	5	1	3	1/3	7	1/3	5	0.0988
W-Sig	3	3	1/3	1/3	5	1/3	1	1/3	7	1/3	5	0.0840
Sigfox	3	3	1/3	1/3	5	3	3	1	9	1/3	5	0.1189
LTE	1/7	1/7	1/9	1/9	1/5	1/7	1/7	1/9	1	1/7	1/5	0.0119
LoRa	3	3	3	3	5	3	3	3	7	1	5	0.2110
NB-IoT	1/3	1/3	1/5	1/5	1/3	1/5	1/5	1/5	5	1/5	1	0.0255

Consistency ratio of this matrix is 0.0935.

iii. Complexity

Most of the low range IoT technologies show lower complexity according to the last colomn of Table 20. Wide area technologies have medium level of complexities whereas LTE shows low complexity even being a wide area technology. So the short range technology with lower complexity levels are given low weight values in pairwise comparisons. For example, BLE is given a weight value of 5 when compared with EnOcean. If we take LoRa and NB-IoT, the former is just a little less complex than the latter, so we give LoRa a weight value of 3 in pairwise comparison with NB-IoT. All the technologies are mapped according to their complexlity levels in Table 17.

Table 17 Pairwise Comparison Matrix for IoT technologies with respect to 'Complexity'

Complexity	RFID	NFC	BLE	EnOcean	WiFi	Zigbee	W-Sig	Sigfox	LTE	LoRa	NB-IoT	Priority Vector
RFID	1	1/3	3	5	3	7	3	3	3	3	5	0.1687
NFC	3	1	3	5	3	7	3	3	3	3	5	0.2122
BLE	1/3	1/3	1	5	3	7	3	3	3	3	5	0.1397
EnOcean	1/5	1/5	1/5	1	1/5	3	1/5	1/5	1/5	1/5	1/3	0.0223
WiFi	1/3	1/3	1/3	5	1	5	1/3	1/3	1/3	1/3	3	0.0537
Zigbee	1/7	1/7	1/7	1/3	1/5	1	1/7	1/7	1/7	1/7	1/5	0.0136
W-Sig	1/3	1/3	1/3	5	3	7	1	1/3	1/3	1/3	3	0.0676
Sigfox	1/3	1/3	1/3	5	3	7	3	1	3	3	3	0.1122
LTE	1/3	1/3	1/3	5	3	7	3	1/3	1	1/3	3	0.0802
LoRa	1/3	1/3	1/3	5	3	7	3	1/3	3	1	3	0.0948
NB-IoT	1/5	1/5	1/5	3	1/3	5	1/3	1/3	1/3	1/3	1	0.0349

Consistency ratio of complexity sub-criteria matrix is calculated to be 0.0978.

5.6 Results and Final Rankings

Based on these calculations we can now finally rank the IoT technologies against all the criteria. For this, we first construct a matrix taking priority vectors of all the sub criteria matrices. Here is the matrix.

Table 18 Matrix of all the priority vectors

Range	Latency	Data rate	Accuracy	Battery life	Privacy & security	Availability	Power consumption	Cost	Complexity
0.0134	0.0688	0.0369	0.0517	0.0296	0.1571	0.1946	0.0537	0.1736	0.1687
0.0170	0.0781	0.0448	0.0189	0.1874	0.1134	0.1946	0.0537	0.1736	0.2122
0.0227	0.2427	0.0792	0.0825	0.0296	0.0371	0.1946	0.1408	0.0679	0.1397
0.0385	0.0454	0.0239	0.0201	0.1874	0.0183	0.0604	0.1700	0.0156	0.0223
0.0390	0.1147	0.3377	0.2371	0.0117	0.0183	0.0932	0.0317	0.0684	0.0537
0.0528	0.1855	0.0296	0.0420	0.0588	0.1571	0.0233	0.0988	0.1551	0.0136

0.0784	0.0330	0.1652	0.0262	0.0588	0.1571	0.0181	0.0840	0.0742	0.0676
0.2680	0.0137	0.0141	0.1088	0.0234	0.0371	0.0932	0.1189	0.1482	0.1122
0.1608	0.1716	0.1586	0.1483	0.0874	0.1430	0.0509	0.0119	0.0203	0.0802
0.1216	0.0206	0.0176	0.0920	0.1810	0.0183	0.0424	0.2110	0.0741	0.0948
0.1878	0.0259	0.0924	0.1726	0.1448	0.1430	0.0345	0.0255	0.0291	0.0349

Multiplying this matrix with the criteria matrix that contains relative priorities off all the sub-criteria. It results into overall priority values of all the IoT technologies considered in this problem based on all the 10 criteria. From there, we can rank all of these technologies. Here is the final priority vector with final rankings of the considered alternatives.

Table 19 Final Score of all the IoT technologies and final rankings

Alternative	Final Score	Final Rank
SigFox	0.1484	1
LTE	0.1327	2
NB-IoT	0.1235	3
WiFi	0.1003	4
BLE	0.0922	5
LoRa	0.0824	6
Zigbee	0.0767	7
RFID	0.0698	8
NFC	0.0678	9
Weightless SIG	0.0638	10
EnOcean	0.0403	11

Subjective and quantitative analysis based weight values were used and the corresponding AHP results are presented in the table. These values are not shown on the AHP figure for clarity reasons. Sigfox is ranking first among all 11 considered IoT technologies. Since we considered regular individuals and their overall well-being in addition to neurologically challenged people for the healthcare system, so accuracy played a big role in the overall decision of selecting an appropriate IoT technology for the proposed system. Even the other wide area solutions with low power are showing good rankings too.

6. CONCLUSION AND OUTLOOK

The IoT has impacted almost all the essential aspects of our daily lives. It certainly has potential to assist many different sectors with their core businesses and on top of that it can give value added services to them. Likewise, situation awareness has a lot to do with the normal functioning of an individual or an enterprise. It can help identify potential threats and unwanted consequences associated with a particular situation. Situation Awareness is kind of a risk management strategy that helps knowing different factors of an environment in advance so that necessary actions can be taken. In this paper, we have tried and explored the potential of different IoT technologies to achieve situational awareness. And as a use case we have selected a healthcare system that would help individuals monitor their normal health related activities and specifically focus the elderly people who are suffering with any stage of dementia. IoT technologies can well serve the purpose of providing better medical care and eventually enhancing the quality of life. In the health sector, there can be a number of situations, for example, tracking and monitoring of an individual who is neurologically challenged, remote treatment of patients and some emergency cases in which a person is outside of a medical facility, here sensors can play their part. A network in which different kinds of sensors are coordinating with each other can make the treatment process a lot better. We have analyzed the role of 11 different IoT technologies – both short range and wide area solution – against 3 main and 10 sub-criteria to help a healthcare system with such scenarios. Analytical Hierarchy Process was used to select the best alternative. Sigfox is the top ranked IoT technology for the purpose. Every technology that was considered had its benefits, we focused on the qualities which are most important for the proposed healthcare system. Sigfox is found to be pretty affordable, simple to implement, not needing a lot of resources, has ability to handle the scenarios we talked above efficiently. Size of the equipment and the ease of use it provides to its users are key factors which decide the acceptance of the proposed system for the individuals. Sigfox is foud better than some of the other considered technologies as it reduces the cost of buying and operating the medical equipment. There is no need to connect intermediate GSM hubs or ADSL to the healthcare staff. Sigfox gives better autonomy to battery size ratio that results into more comfort and better user experience. Because of its compatibility both indoor and outdoor, it enables the individuals to be independance while they are under medical supervision. Moreover, reduces the electromagnetic radiation on the objects which are worn continuoulsly on a daily basis.

Other low power wide area technologies performed really well, NB-IoT, for example. For its proper functioning, NB-IoT, as the name suggests, just takes a narrow band of frequency. Another plus point of it is the deployment in cellular and also in non-cellular form. There are situations that have high intensity and short lived demands, for these, NB-IoT can give quite a wide range with low data rates for coordinated-sensor networks with low complexity of device processing and very good battery life. However, latency is one of the weak points of NB-IoT. Some applications require to work in real time and low latency is essential. In that respect, there are technologies that work better than this.

We are focusing specifically on the elderly people and those who are suffering with dementia, so accuracy of the system, as low as possible latency, and its errorless functioning are of prime importance. Sigfox has showed a great potential for the healthcare system. We discussed a number of times in the previous sections that the best choice from the IoT perspective would depend upon different factors, mainly on the application for which it would be used. We are considering people of different ages, different health condition, possibly some patients as well who would probably be staying indoor more often than others. So there are technologies that would work better in different scenarios. WiFi is top ranked among solutions which are suitable for short or medium ranges.

For cellular technology, in the analytical analysis we have used most of the values of LTE, but we have also considered 5G. The lowest point of cellular technology was found to be it way too much power consuming, probably the worst among considered technologies, otherwise, it offers a number of benefits over others. If the expected parameters of 5G are met in coming days, it may well prove to be revolutionary in the healthcare sector.

REFERENCES

[1] Situation Awareness , Online Available at : https://en.wikipedia.org/wiki/Situation_awareness#cite_note-14

[2] The National Of Academies , Modeling Human And Organizational Behavior , Available Online at : https://www.nap.edu/read/6173/chapter/9#176

[3] Expert System , Online Available at : https://en.wikipedia.org/wiki/Expert_systems

[4] Bayesian network , Online Available at : https://en.wikipedia.org/wiki/Bayesian_network

[5] Artificial Intelligence ,Case Based Reasoning , Online Available at : https://artint.info/html/ArtInt_190.html

[6] Artificial Intelligence , Case-Based Reasoning , Online Available at : https://en.wikipedia.org/wiki/Case-based_reasoning

[7] Accelerating The Industrial Internet Of Things , Situational Awareness, Online Available at : https://www.iotone.com/term/situational-awareness/t664

[8] Fuzzy Set , Online Available at : https://en.wikipedia.org/wiki/Fuzzy_set

[9] Analytic Hierarchy , Online Available at : https://en.wikipedia.org/wiki/Analytic_hierarchy_process

[10] T R B Publications Index , Application Of Analytic Hierarchy Process To Select Project Scope For Video logging And Pavement Condition Data Collection , Online Available at : http://pubsindex.trb.org/view.aspx?id=801508

[11] Dataversity , Data Topics , Online Available at : https://www.dataversity.net/virtual-hospitals-changing-healthcare-iot/

[12] Sam Solutions ,Internet Of Things In Health Care : IoT Connected Medical Devices , Online Available at : https://www.sam-solutions.com/blog/internet-of-things-in-healthcare-iot-connected-medical-devices/

[13] Econsultancy,10 Examples of the Internet of Things in Health care,Avalaible Online at :https://econsultancy.com/internet-of-things-healthcare/

[14] Life log, Available online at :https://en.wikipedia.org/wiki/Life log

[15] Forbes, Available Online at:https://www.forbes.com/sites/shour-jyasanyal/2018/11/26/are-hearables-the-new-wearables-revolutionizing-healthcare/#9222c81674bb

[16] Data Driven Investor, Ambient Assisted living: A Step Towards A Smart Living, Available Online at:https://medium.com/datadriveninvestor/ambi-ent-assisted-living-a-step-towards-a-smart-living-ea84a746affc

[17] Joost Broekens, Marcel Heerink, and Henk Rosendal, Assistive social Robots In elderly care: a review, Available Online at:http://citese-erx.ist.psu.edu/viewdoc/down-load?doi=10.1.1.714.6939&rep=rep1&type=pdf

[18] Nadeen R.Rishani, Hadeel Alayan, Raed M.Shubair, and Asimina Kiourti,2018,Wearable Epidermal And Implant Sensors for Medical Applications, Available Online at : https://arxiv.org/pdf/1810.00321.pdf

[19] EMB, Wearable And Implantable Technologies, Available Online at:https://www.embs.org/about-biomedical-engineering/our-areas-of-re-search/wearable-implantable-technologies/

[20] IEEE Xplore, An Extraction Method Of Situational Factors for Network Security Situational Awareness, Published in: 2008 International Conference on Internet Computing in Science and Engineering 2008. Available online at: https://ieeexplore.ieee.org/document/4548281

[21] Ehsan Moradi-Pari, and Oubada Abuchaar Amin Tahmasbi-Sar-vestani,Hossein Nourkhiz Mahjoub, Yaser P. Fallah, Implementation and Evaluation of a Cooperative Vehicle-to-Pedistrian Safety Application. Available online at https://arxiv.org/abs/1808.06463-

[22] IEEE Xplore, Situation Awareness Measurement Enhanced for Efficient Monitoring In The Internet of Things, Published in: 2015 IEEE Region 10 Symposium 2015. Available online at: https://ieeexplore.ieee.org/docu-ment/7166243

[23] Aya Hussein, Hussein Abbass, Mixed Initiative Systems For Human-Swarm Interactions: Opportunities And Challenges, Available Online at: https://arxiv.org/abs/1808.06211

[24] IEEE Xplore, Network security situational assessment model based on AHP_FCE, Published in: 2013 Sixth International Conference on Advanced Computational Intelligence (ICACI) 2013. Available Online at: https://ieeexplore.ieee.org/document/6748501

[25] Rahim Jassemi-Zargani, Fredrick Lickacz, Nathan kashysp, Defence Research and Development Canada, Situational Awareness Effectiveness Using AHP, Available Online at: http://www.isahp.org/uploads/p744085.pdf

[26] ResearchGate, Architecture For Latency Reduction In Health Care Internet-of-Things using Reinforcement Learning and Fuzzy Based Fog Computing: Proceedings of The 3rd International Conference Of Reliable Information And Communication Technology(IRICT 2018),Available Online at: https://www.researchgate.net/publication/327545819_Architecture_for_Latency_Reduction_in_Healthcare_Internet-of-Things_Using_Reinforcement_Learning_and_Fuzzy_Based_Fog_Computing_Proceedings_of_the_3rd_International_Conference_of_Reliable_Information_a

[27] IEEE Innovation, Why We Need Low-Power, Low-Latency Devices, Available Online at:https://innovationatwork.ieee.org/why-we-need-low-power-low-latency-devices/

[28] Wireless IOT Net -Working-Why Data Rates Matter, Available Online at: https://www.morsemicro.com/blog/wifi-data-rate

[29] 5G?IoT,Available Online at: https://whatis5g.info/energy-consumption/

[30] 5 Reasons Privacy and IoT are Incompatible, Available Online at:https://www.iotforall.com/five-reasons-privacy-iot-incompatible/

[31] Nathan Eddy, Data breach costs continue to rise across healthcare industry. Available online at: https://www.healthcareitnews.com/news/data-breach-costs-continue-rise-across-healthcare-industry

[32] Link Labs, NB-IoT vs. LoRa vs. Sigfox, Available Online at: https://www.link-labs.com/blog/nb-iot-vs-lora-vs-sigfox

[33] IoT World Today, IoT Connectivity Options: Comparing Short-long Range Connectivity, Available Online at:https://www.iotworldtoday.com/2018/08/19/iot-connectivity-options-comparing-short-long-range-technologies/

[34] Postscapes, IoT Technology Guidebook, Available Online at: https://www.postscapes.com/internet-of-things-technologies/

[35] Science Direct, RFID Applications and Adoptions in HealthCare, Available Online at: https://www.sciencedirect.com/science/article/pii/S1877050918316430

[36] Ms.Harneet Kaur, Ms.Sukesha Sharma, A Comparative Studies of Wireless Technologies: Zigbee, Bluetooth LB, EnOcean, Wavenis, Insteon and UWB, Available Online at:https://pdfs.semanticscholar.org/edb0/8646e3583204131de9462a566c607b305f88.pdf

[37] Vladimir Stantchev, Corvin Jaedicke, Gerrit Tamm,The Internet Of Things And Smart Items- Fog Computing Architectures For Healthcare, Available Online at: https://www.academia.edu/29738799/The_Internet_of_Things_and_Smart_Items_Fog_Computing_Architectures_for_Healthcare

[38] Me and My Smarter World, 6 ways NFC helps Healthcare, Available Online at: https://blog.nxp.com/iot/6-ways-nfc-helps-healthcare

[39] ACM DL , Experiencing NFC- Bases Touched for Home Healthcare, Available Online at: https://dl.acm.org/citation.cfm?id=1579141

[40] The Growing Significance Of Bluetooth BTLE in Healthcare, Available Online at: https://orthogonal.io/insights/the-growing-significance-of-bluetooth-btle-in-healthcare-html/

[41] CENTRAK, The Buzz About BLE: Bluetooth Low Energy In Healthcare, Available Online at:https://www.centrak.com/blog-bluetooth-low-energy-in-healthcare/

[42] Bluetooth Low Energy , Available Online at: https://en.wikipedia.org/wiki/Bluetooth_Low_Energy

[43] SURE, What Is Weightless SIG and Why It Matters, Available Online at: https://www.sureuniversal.com/the-importance-of-the-weightless-sig/

[44] Weightless (Wireless Communications), Available Online at:https://en.wikipedia.org/wiki/Weightless_(wireless_communications)

[45] SPARK, 11 Internet of Things(IoT) protocols you need to Know About, Available Online at: https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about

[46] What is Cellular IoT, Available Online at: https://www.iotforall.com/what-is-cellular-iot/

[47] Zigbee, Wireless protocol, Available Online at: https://en.wikipedia.org/wiki/Zigbee

[48] SEMTECH, Smart Healthcare, Available Online at: https://www.semtech.com/lora/lora-applications/smart-healthcare

[49] ZENTIS, LoRa, IoT for Medical devices, Available online at:https://www.zentis.nl/en/blog/LoRa-as-a-means-of-communication-for-medical-devices

[50] GSMA, NarrowBand-Internet of things, Available Online at:https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/

[51] Science Direct, NarrowBand- IoT performance Analysis for Healthcare Applications, Available online at: https://www.sciencedirect.com/science/article/pii/S1877050918305192

[52] Science Direct, A comparative study of LPWAN Technologies for large scale IoT deployment, Available Online at: https://www.sciencedirect.com/science/article/pii/S2405959517302953

[53] MUO, The Most Common WiFi Standards and Types Explained, Available Online at:https://www.makeuseof.com/tag/understanding-common-wifi-standards-technology-explained/

[54] Chron, How Far Can Wireless Work ?, Available Online at:https://smallbusiness.chron.com/far-can-wireless-work-60665.html

[55] Jussi Timonen, The Finnish Defense Forces, C5 Agency, Jyväskylä, Finland. Improving situational awareness of cyber physical systems based on operator's goals. Published in: 2015 International Conference on Cyber Situational Awareness, Data Analytics and Assessment (CyberSA) – 2015. Available online at: https://ieeexplore.ieee.org/document/7166121

[56] Huiqiang Wang ; Ying Liang ; Haizhi Ye, an Extraction Method of Situational Factors for Network Security Situational Awareness. Published in: 2008 International Conference on Internet Computing in Science and Engineering Available online at: https://ieeexplore.ieee.org/document/4548281

[57] Michael Davies; Menisha Patel, Are we managing the risk of sharing cyber situational awareness? A UK Public Sector case study, Published in: 2016 International Conference on Cyber Situational Awareness, Data Analytics and Assessment (CyberSA). Available online at: https://ieeexplore.ieee.org/document/7503292

[58] Eliana Stavrou, Enhancing Cyber Situational Awareness: A New Perspective of Password Auditing Tools, Published in: 2018 International Conference On Cyber Situational Awareness, Data Analytics And Assessment (Cyber SA). Available online at: https://ieeexplore.ieee.org/document/8551404

[59] Cyril Onwubiko, Security operations center: Situation awareness, threat intelligence and cybercrime Published in: 2017 International Conference on Cyber Situational Awareness, Data Analytics and Assessment (Cyber SA). Available online at: https://ieeexplore.ieee.org/document/8073384

[60] Ahmed Al-Shamisi; Panos Louvieris; Mohammed Al-Mualla; Martin Mihajlov, towards a theoretical framework for an active cyber situational awareness model. Published in: 2016 International Conference on Systems, Signals and Image Processing (IWSSIP). Available online at: https://ieeexplore.ieee.org/document/7502753

[61] Maria Evangelopoulou; Christopher W. Johnson, Empirical framework for situation awareness measurement techniques in network defense. Published in: 2015 International Conference on Cyber Situational Awareness, Data Analytics and Assessment (CyberSA). Available online at: https://ieeexplore.ieee.org/document/7166132

[62] Kais Mekki, Eddy Bajic, Frederic Chaxel, Fernand Meyer. The Korean Institute of Communications and Information Sciences, 2018. Available online at: https://www.sciencedirect.com/science/article/pii/S2405959517302953

[63] Won Chul Cha, The Effectiveness of Near-Field Communication Integrated with a Mobile Electronic Medical Record System: Emergency Department Simulation Study, first published in JMIR mhealth and uhealth in 2018. Available online at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6231820/

[64] Mahmoud Shuker Mahmoud, Auday Mohamad- A Study of Efficient Power Consumption Wireless Communication Techniques/ Modules for Internet of Things (IoT) Applications VL - 06 Advances in Internet of Things - 2016. Available online at https://www.researchgate.net/publication/301597433_A_Study_of_Efficient_Power_Consumption_Wireless_Communication_Techniques_Modules_for_Internet_of_Things_IoT_Applications

[65] Zafari, Faheem; Gkelias, Athanasios; Leung, Kin. A Survey of Indoor Localization Systems and Technologies. Publication: eprint arXiv:

1709.01015 - Publish Date: September 2017. Available online at: https://arxiv.org/abs/1709.01015

[66] Silva PFE, Kaseva V, Lohan ES. Wireless Positioning in IoT: A Look at Current and Future Trends. Sensors (Basel). 2018; 18(8):2470. Published 2018. Available online at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6111536/

[67] Saeedreza Arab, Hossein Ashrafzadeh, Amir Alidadi - Internet of Things: Communication Technologies, Features and Challenges - Published IJEDR 2018 | Volume 6, Issue 2 | ISSN: 2321-9939 - Available online at: https://www.ijedr.org/papers/IJEDR1802136.pdf

[68] Shreyas Sen, Jinkyu Koo, Saurabh Bagchi - TRIFECTA: Security, Energy-Efficiency, and Communication Capacity Comparison for Wireless IoT Devices - Published in: IEEE Internet Computing (Volume: 22, Issue: 1, Jan. /Feb. 2018). Available online at: https://ieeexplore.ieee.org/document/8307733

[69] Sukesha Sharma - A Comparative Study of Wireless Technologies: Zigbee, Bluetooth LE, EnOcean, Wavenis, Insteon and UWB - Conference: Proc. of the Intl. Conf. on Recent Trends in Computing and Communication Engineering--RTCCE March 2013. Available online at: https://www.researchgate.net/publication/297914160_A_Comparative_Study_of_Wireless_Technologies_Zigbee_Bluetooth_LE_Enocean_Wavenis_Insteon_and_UWB

[70] Chathura Withanage; Rahul Ashok ; Chau Yuen ; Kevin Otto - A comparison of the popular home automation technologies - Published in: 2014 IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA) 2014 - Available online at : https://ieeexplore.ieee.org/abstract/document/6873860

[71] D. Feil-Seifer; M.J. Mataric - Defining socially assistive robotics - Published in: 9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005. Available online at: https://ieeexplore.ieee.org/document/1501143

[72] Parag Chatterjee ; Leandro J. Cymberknop ; Ricardo L. Armentano - IoT-based decision support system for intelligent healthcare — applied to cardiovascular diseases - Published in: 2017 7th International Conference on Communication Systems and Network Technologies (CSNT) 2017. Available online at: https://ieeexplore.ieee.org/document/8418567

[73] Nikos Dimitrioglou ; Dimitris Kardaras ; Stavroula Barbounaki. Multicriteria evaluation of the Internet of Things Potential in Health Care. The case of Dementia Care. Published in: 2017 IEEE 19th Conference on Business Informatics (CBI). Available online at: https://ieeexplore.ieee.org/document/8010750

[74] Zainab Alansari ; Nor Badrul Anuar ; Amirrudin Kamsin ; Safeeullah Soomro ; Mohammad Riyaz Belgaum. The Internet of Things adoption in healthcare applications. Published in: 2017 IEEE 3rd International Conference on Engineering Technologies and Social Sciences (ICETSS). Available online at: https://ieeexplore.ieee.org/document/8324138

[75] Kais Mekki; Eddy Bajic; Frederick Chaxel; Frenand Meyer. A comparative study of LPWAN technologies for large scale IoT deployment. Published in: 2019 ICT Express. The Koreon Institute Of Communications and Information Sciences. Available online at: https://www.sciencedirect.com/science/article/pii/S2405959517302953

[76] Saeedreza Arab; Hossein Ashrafzadeh; Amir Alidadi. Internet of Things: Communication Technologies, Features and Challenges. Published in: 2018 |Volume 6, Issue 2|ISSN 2321-9939. Available online at: https://www.ijedr.org/papers/IJEDR1802136.pdf

[77] Faheem Zafari; Student Member; IEEE, Athanasios Gkelias; Senior Member, IEEE, Kin K. Leung, Fellow, IEEE. A Survey of Indoor Localization Systems and Technologies. Published in: 2019. Available online at: https://arxiv.org/pdf/1709.01015.pdf

[78] Pedro Figueiredo e Silva; Ville Kaseva; Elena Simona Lohan. Wireless Positioning in IoT: A Look at Current and Future Trends. Published in: 2018 PMC US National Library of Medicine National Institute of Health. Available online at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6111536/

[79] Maciej Rygielski. IoT Radio Technologies comparison. Published in: 2018 RAPIDLAB. Available online at: https://rapidlab.io/blog/iot-radio-technologies-comparison/

[80] Patrick Mannion, Contributed by Digi-Key's North American Editors. Comparing Low-Power Wireless Technologies (Part 1). Published in: 2017 Article Library. Available online at: https://www.digikey.fi/en/articles/techzone/2017/oct/comparing-low-power-wireless-technologies

[81] Vladan Koncar.Toward wireless structural health monitoring. Published in the book Smart Textiles for In Situ Monitoring of Composites, 2019. Chapter available online at: https://www.sciencedirect.com/topics/engineering/near-field-communication

[82] Rohde; Schwarz. Near Field Communication (NFC) Technology and Measurements, White Paper. Published in: 2011 1MA182_5e. Available online at: https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ma182/1MA182_5E_NFC_WHITE_PAPER.pdf

[83] Tab latency Explained. World Wide OpenFare. Available online at: https://wwopenfare.com/tap-latency-explained/

[84] Haroor Singh; Prof.Sukhwinder Singh. Near Field Communication (NFC). Published in: 2014 International Journal of Enhanced Research in Science Technology and Engineering. Available online at: https://pdfs.semanticscholar.org/b164/c43503c83294273124e668dc4362a75d689b.pdf

[85] Sriramulu Bojjagani; V.N.Sastry. A secure end-to-end proximity NFC-based mobile payment protocol. Published in: 2019 ELSEVIER, Computer Standards and Interfaces. Available online at: https://www.sciencedirect.com/science/article/abs/pii/S0920548918302253

[86] Wearables, Smart Textiles and Smart Apparel. Published in: 2019. Available online at: https://www.sciencedirect.com/topics/engineering/wi-fi

[87] Renato Miyagusuku; Atsushi Yamashita; Hajime Asama. Precise and accurate wireless signal strength mappings using Gaussian processes and path loss models. Published in: 2018 ELSEVIER, Robotics and Autonomous Systems. Available online at: https://www.sciencedirect.com/science/article/abs/pii/S0921889017303925?via%3Dihub

[88] Giuseppe Caso; Luca De Nardis; Gabriella Di Benedetto. Low -Complexity Offline and Online Strategies for Wi-Fi Fingerprinting Indoor Positioning Systems. Published in: 2019 ACADEMIC PRESS, Geographical and Fingerprinting Data to Create Systems for Indoor Positioning and Indoor\Outdoor Navigation. Available online at: https://www.sciencedirect.com/science/article/pii/B9780128131893000071

[89] Nikolaos Tsavalos; Ahmad Abu Hashem. Low Power Wide Area Netword (LPWAN) Technologies for Industrial IoT Applications. Published in: 2018 SE-22100 Lund, Sweden. Available online at: https://www.eit.lth.se/sprapport.php?uid=1134

[90] William G.Wong. Choices Abound for Long-Range Wireless IoT. Published in: 2017 ElectronicDesign. Available online at: https://www.electronicdesign.com/industrial-automation/choices-abound-long-range-wireless-iot

[91] Joseph Finnegan; Stephan Brown. A Comparative Survey of LPWA Networking. Published in: 2018. Available online at: https://arxiv.org/pdf/1802.04222.pdf

[92] S.Marksteiner; V. J. Exposito Jimenez; H. Vallant; H. Zeiner. An Overview of Wireless IoT Protocol Sceurity in the Smart Home Domain. Published in: 2017 Joint 13th CTTE and 10th CMI Conference on Internet of Things Business Models, Users, and Networks, Copenhagen, 2017, pp. Available online at: https://arxiv.org/pdf/1801.07090.pdf

[93] Chathura Withanage; Rahul Ashok; Chau Yuen; Kevin Norbert Otto. A comparison of the popular home automation technologies. Published in: 2014 IEEE Innovative Smart Gird Technologies- Asia (ISGT ASIA). Available online at: https://www.researchgate.net/publication/269269896_A_comparison_of_the_popular_home_automation_technologies

[94] Natalie Hogan, Comparing Internet of Things (IoT)-Based Asset Tracking Technologies: RFID vs. BLE. Available online at: https://www.bastiansolutions.com/comparing-internet-of-things-iot-based-asset-tracking-technologies-rfid-vs-ble/

[95] Zigbee vs WiFi – Difference between Zigbee and Wifi. Available online at: https://www.rfwireless-world.com/Terminology/zigbee-vs-wifi.html

[96] Eun-Kyu Lee; Young Min Yoo; Chan Gook Park; Min-Soo Kim. Installation and evaluation of RFID readers on moving vehicles. Published in: 2009 Proceedings of the Sixth International Workshop on Vehicular Ad Hoc Networks. Available online at: https://www.researchgate.net/figure/Average-read-latency-with-varying-pitch-angles-of-RFID-reader-antennas_fig5_220926713

[97] David Sembroiz, Davide Careglio, Chapter 10 - A Novel Cloud-Based IoT Architecture for Smart Building Automation. Security and Resilience in

Intelligent Data-Centric Systems and Communication Networks. Available online at: https://www.sciencedirect.com/topics/engineering/bluetooth

[98] Olof Liberg, Joachim Sachs, Cellular Internet of Things. Published in: 2018. Available online at: https://www.sciencedirect.com/topics/engineering/battery-life

[99] Official link of the Weightless: http://www.weightless.org/keyfeatures/security

[100] Simon Hill. 5G vs. 4G: How will the next generation improve on the last?. Published in: 2019 DIGITAL TRENDS. Available online at: https://www.digitaltrends.com/mobile/5g-vs-4g/

[101] Hugo Landaluce; Asier Perallos; Ignacio Angulo. Managing the Number of Tag Bits Transmitted in a Bit-Tracking RFID Collision Resolution Protocol. Published in: 2014 PMC US National Library of Medicine National Institute of Health. Available online at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3926599/

[102] Vahidnia, Mohammad H. & Alesheikh, Ali & Alimohammadi, Abbas & Bassiri, A. (2008). Fuzzy analytical hierarchy process in GIS application. 37. Available online at: https://www.researchgate.net/publication/228406167_Fuzzy_analytical_hierarchy_process_in_GIS_application

[103] Yap, Jeremy & Ho, Chiung Ching & Yee, Ting. (2017). Analytic Hierarchy Process (AHP) for business site selection. AIP Conference Proceedings. 2016. 10.1063/1.5055553. Available online at: https://www.researchgate.net/publication/316736276_Analytic_Hierarchy_Process_AHP_for_business_site_selection

[104] Li, L., Guo, C., Liu, Y., Zhang, L., Qi, X., Ren, Y. Chen, F. (2018). Accurate Device-Free Tracking Using Inexpensive RFIDs. Sensors (Basel, Switzerland), 18(9), 2816. doi:10.3390/s18092816. Available online at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6163575/

APPENDIX: COMPARISON DATA FOR THE CHOSEN IOT TECHNOLOGIES

The data accumulated for the comparison matrices of the IoT technologies with respect to all ten sub-criteria is given in the table 21.

Table 20 Data for comparison matrices of IoT technologies

	Accuracy	Range	Latency	Data Rate	Power consumption	Privacy & security	Availability	Battery life	Cost	Complexity
RFID	32cm [104]	0-10 cm [76]	Low [101]	256kbps [96]	ultralow [98]	High	High [94]	20 years [94]	0.10$ [94]	Low [103]
Enocean	Low [78]	30m [76]	Low	125kbs [92]	Ultralow [92]	CBC, CMAS [92]	Med	No need [93]	High [92]	Med
NFC	1-2cm [82]	20cm [81]	100-250ms [83]	424kbit/s [84]	ultralow [81]	Secured via encryption [82]	High [81]	No need [81]	$0.10 [81]	Low [85]
BLE	Med [78]	100m [97]	2.5ms [80]	732kbps-3mbps [76]	0dbm(1mw) 4dbm(2.5mw) [76]	AES,pim code [76]	High [92]	1 to 7 days [76]	5-30$ [79]	Low [92]
W-SIG	N, med P, Low W, med [78]	2km per P, 3km per N, 5km per W [77]	Low [93]	200bps-100kbps [91]	low [93]	AES-128/256bits [99]	Low	Med	Low [91]	Med [91]
SigFox	High[75]	40km(rural) 10km (urban)[75]	6-9 s[91]	10bps [75]	Very low [76]	AES 128bit [76]	High [91]	>10 years [76]	>2$ [75]	Low
LTE	High	35km [79]	20ms[100]	100 Mbps	5000 mW [79]	Highly secure [79]	High	>10years	30-50$ [79]	Low
Zigbee	Med [78]	300m [76]	20ms [80]	250 kbps [76]	0.39 watts [95]	AES 128bit [76]	Med	10-1000days [76]	Ultra low [76]	Med
LoRa	Low[75]	5km(urban) 20km(rural) [75]	Med [91]	50kbps[75]	Low [76]	Low [76]	Med [91]	>10years [76]	3-5$ [75]	Med
NB-IoT	Med [78]	1km(urban) 10km (rural) [75]	1.6 to 10 s[90]	200kbps [75]	500 mW [98]	High [89]	Med [89]	11years [89]	>20$ [75]	Med [89]
WiFi	High [87]	125m [76]	105ms [80]	1.3Gbps[76]	High [86]	WPA,WEP [76]	High	1-5days [76]	Medium [76]	Low [88]